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Latest Ordovician Solitary Rugose Corals

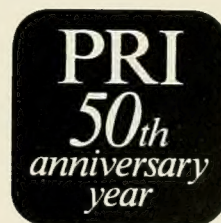
of

Eastern North America

by

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LATEST ORDOVICIAN SOLITARY RUGOSE CORALS OF EASTERN NORTH AMERICA

By

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ABSTRACT

This study comprises comprehensive taxonomic, paleoecologic, biostratigraphic, and paleobiogeographic analyses of latest Ordovician (Richmondian and Gamachian; Ashgill) solitary rugose corals in eastern North America. The corals are assigned to three provinces distinguished on the basis of assemblages and characteristic species. The distribution of these provinces, as well as taxa within them, was determined by regional environmental parameters related to paleogeography. During Richmondian time, the Richmond Province occupied a narrow belt extending northward from the Nashville Dome of Tennessee, along the Cincinnati Arch region of Kentucky, Indiana, and Ohio to northern Michigan, and eastward through southern Ontario and Québec. It coincided with a carbonate platform at the margin of an epicontinental sea that was receiving clastic sediments from the Queenston delta (Ontario, New York, Pennsylvania, and Ohio). Solitary coral diversity was low, but variability within several species was high. The following taxa were present: *Streptelasma divaricans* (Nicholson, 1875b), *Grewingkia canadensis* (Billings, 1862), *G. deltensis* n. sp., and *G. rustica* (Billings, 1858a). This province was isolated by the positive Canadian Shield, Taconic Mountains, and Nashville Dome, and by deeper water in which the Maquoketa Group shale of the upper Mississippi valley was deposited.

Solitary corals in the Maquoketa Group and those at the eastern continental margin belonged to the Red River–Stony Mountain Province, which included most of North America during the Late Ordovician. The vast continental interior portion was occupied by shallow, interconnected epicontinental seas, whereas normal open marine environments were present at the continental margins. The Maquoketa Subprovince was characterized by the paucity and very low diversity of solitary corals in carbonate beds within shales of the Maquoketa Group. The following taxa were present: *Helicelasma randi* Elias (1981) and *Bighornia* cf. *B. patella* (A. E. Wilson, 1926). The diverse assemblage associated with carbonate sequences in the Maritime Subprovince (Anticosti Island and the Gaspé Peninsula of Québec, and northern Maine) included typical continental interior species together with genera characteristic of North American continental margins and Baltoscandia. The following taxa were present: *Streptelasma rankini* n. sp., *S. affine* (Billings, 1865), *Helicelasma selectum* (Billings, 1865), *Deiracorallium angulatum* (Billings, 1862), *Grewingkia penobscotensis* n. sp., *G. pulchella* (Billings, 1865), *Grewingkia* sp., *Lobocorallium trilobatum vaurealense* (Twenhofel, 1928), *Kenophyllum?* sp., *Bodophyllum neumani* n. sp., *Bodophyllum?* sp., *B. englishheadense* n. sp., *Bighornia* cf. *B. patella* (A. E. Wilson, 1926), and *Paliphyllum ellisense* (Twenhofel, 1928).

At the end of Richmondian time, regression of the eastern North American epicontinental sea resulted in extinction of corals in the Richmond Province and Maquoketa Subprovince. The latest Ordovician (?Gamachian) Edgewood Province coincided with a carbonate sequence deposited in normal open marine environments during a transgression into the continental interior (upper Mississippi valley). The solitary corals resembled those previously restricted to continental margins, and foreshadowed the cosmopolitan Silurian fauna. The following taxa were present: *Streptelasma leemonense* n. sp., *Streptelasma* sp., *S. subregulare* (Savage, 1913), and *Bodophyllum shorti* n. sp.

INTRODUCTION

This study comprises comprehensive taxonomic, paleoecologic, biostratigraphic, and paleobiogeographic analyses of latest Ordovician (Richmondian and Gamachian; Ashgill) solitary rugose corals in eastern North America (Text-figs. 1, 2).

Field work in Missouri, Tennessee, Kentucky, Indiana, Ohio, northern Michigan, and southern Ontario in the summers of 1977 and 1978 provided extensive collections as well as paleoecologic and stratigraphic data. To ensure stratigraphic control, all sections examined have been described in the literature, or are near described sections (see "Appendix: Collecting

Localities"). The lithology and megafossils were observed at each locality, and an extensive search for solitary corals was made. Where present, their exact stratigraphic position was recorded. Relative abundance was estimated qualitatively (*rare*, *sparse*, *uncommon*, *common*, *abundant*), with *rare* meaning one to several corals were found and *abundant* meaning they were so prolific it was not feasible to collect all the specimens. When possible, orientation on bedding surfaces was noted. All corals seen were collected, except in the few stratigraphic intervals where they were abundant. Almost 1000 specimens were collected for this study.

In the Cincinnati Arch region, 34 localities were examined to prepare composite sections 1 to 14 (Text-fig. 3). Four localities near Burkesville, Kentucky, three in the Goodlettsville-Gallatin area of Tennessee, and three at Little Bay de Noc, Michigan, provided data for composite sections 15, 16, and 17, respectively (Text-figs. 3, 18). Stratigraphy at Drummond and Manitoulin Islands is shown in composite section 18/19 (Text-fig. 18). Three localities were studied on Drummond Island. Of 25 exposures seen on Manitoulin Island, six have important intervals that contain solitary corals. In eastern Missouri, sections 20a and 20b in Cape Girardeau County and sections 21a and 21b in Pike County were examined (Text-fig. 21).

Approximately 1000 corals from many of the above areas and from collections made elsewhere in eastern North America were obtained on loan. Most specimens from the Cincinnati Arch region, Michigan, Ontario, and southwestern Québec were collected by A. F. Foerste. W. H. Twenhofel's extensive collection was the major source of material from Anticosti Island, Québec. Solitary corals from Maine were collected by R. B. Neuman (U.S. Geological Survey, Washington, D.C., U.S.A.).

Morphologic and descriptive terminology used herein for solitary Rugosa follows Hill (1935, 1956) and Elias (1981). To examine internal morphology, most corals were sectioned transversely in several places, and relatively few were sectioned longitudinally. Thin sections of more than 300 specimens have been prepared. Biometric and other data recorded during this study were presented in Elias (1979).

ABBREVIATIONS OF REPOSITORIES

FMNH UC	Field Museum of Natural History, University of Chicago, Chicago, Illinois, U.S.A.
GSC	Geological Survey of Canada, Ottawa, Ontario, Canada
ROM	Royal Ontario Museum, Toronto, Ontario, Canada
SIU	Southern Illinois University, Carbondale, Illinois, U.S.A.
SUI	State University of Iowa, Iowa City, Iowa, U.S.A.
UCGM	University of Cincinnati Geological Museum, Cincinnati, Ohio, U.S.A.
UI	University of Illinois at Urbana-Champaign, Urbana, Illinois, U.S.A.
UMMP	University of Michigan Museum of Paleontology, Ann Arbor, Michigan, U.S.A.

USNM	National Museum of Natural History, Smithsonian Institution, Washington, D.C., U.S.A.
YPM	Peabody Museum, Yale University, New Haven, Connecticut, U.S.A.

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I extend my sincere thanks to Kenneth E. Caster (major advisor), David L. Meyer, and Paul Edwin Potter of the University of Cincinnati, who supervised the doctoral dissertation from which this publication was adapted.

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Loans of specimens were arranged by the following: M. H. Nitecki (FMNH UC), T. E. Bolton (GSC), P. Copper (Laurentian University, Sudbury, Ontario, Canada), J. Waddington (ROM), T. Guensburg (SIU), H. L. Strimple (SUI), D. B. Blake (UI), R. V. Kesling

NORTH AMERICA			EUROPE	
Cincinnati Series	Gamachian Stage		Ashgill Series	Hirnantian Stage
	Richmondian Stage	"Elkhorn"		Rawtheyan Stage
		"Whitewater"		Cautleyan Stage
		"Liberty"		Pusgillian Stage
		"Waynesville"		
		"Arnheim"		
	Maysvillian Stage		Caradoc Series	
Edenian Stage				

Text-figure 1.—Time-stratigraphic subdivisions of the Upper Ordovician for North America (Twenhofel *et al.*, 1954; Sweet and Bergström, 1971) and Europe (Ingham and Wright, 1970), including informal subdivisions of the Richmondian (see Kohut and Sweet, 1968, pp. 1456, 1457, fig. 2).



Text-figure 2.—Latest Ordovician paleogeography and lithofacies in eastern North America. Solitary rugose corals are known from exposures in the numbered areas.

- | | |
|--|---|
| 1. Cincinnati Arch region, Ohio, Indiana, and Kentucky | 12. Northeastern Iowa |
| 2. Burkesville, Kentucky | 13. Southeastern Iowa and northwestern Illinois |
| 3. Goodlettsville-Gallatin area, Tennessee | 14. Thebes, Illinois |
| 4. Little Sturgeon Bay, Wisconsin | 15. Arbuckle Mountains, Oklahoma |
| 5. Little Bay de Noc, Michigan | 16. Cape Girardeau County, Missouri |
| 6. Drummond Island, Michigan | 17. Pike County, Missouri |
| 7. Manitoulin Island, Ontario | 18. Will County, Illinois |
| 8. Meaford, Ontario | 19. Penobscot County, Maine |
| 9. Streetsville, Ontario | 20. Ashland, Maine |
| 10. Montréal, Québec | 21. Percé, Québec |
| 11. Lake St. John, Québec | 22. Anticosti Island, Québec |

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LATEST ORDOVICIAN PALEOGEOGRAPHY, LITHOFACIES, AND SOLITARY RUGOSE CORALS OF EASTERN NORTH AMERICA

OVERVIEW

The Late Ordovician Taconic Mountains along the eastern continental margin of North America were the source of a Richmondian clastic wedge deposited on the craton (R. B. Neuman, 1976; Dennison, 1976; Text-fig. 2). Nearest the uplift, the Juniata Formation comprises continental channel and overbank sandstones with some siltstones and shales. Distally, it consists of lower delta plain redbeds that grade into the grayish-red deltaic shales and siltstones of the Queenston Formation. The Sequatchie Formation and Richmond Group carbonate rocks and shales, and the Maquoketa Group shales were deposited in an epicontinental sea. The Richmond Group thins and the amount of dolomite and terrigenous sand in it increases southward along the Cincinnati Arch region, which was probably a platform, to the positive Nashville Dome. The amount of carbonate and terrigenous sand in the Maquoketa increases and thickness of the group decreases toward the Transcontinental and Wisconsin Arches and the Ozark Dome, which were

slightly positive. In general, Richmondian sedimentation in eastern North America was affected by positive structures rather than by well-defined subsiding basins. The typically regressive stratigraphic sequences may reflect a eustatic sea-level drop accompanying Late Ordovician glaciation centered in Africa (Berry and Boucot, 1973; Dennison, 1976).

Following a period of post-Maquoketa erosion, a thin unit of uppermost Ordovician (?Gamachian) carbonate rocks was deposited in the Arbuckle Mountains area of Oklahoma, in eastern Missouri and western Illinois, and in northern Illinois. These strata represent the initial stage of a transgression that may be related to deglaciation.

On the continental margin, a thick Late Ordovician sequence of carbonate rocks and shale was deposited at Anticosti Island, and a unit including carbonate rocks and mudstone formed on the Gaspé Peninsula. These carbonate rocks grade into very thick sequences of polymict conglomerates, graywackes, and siltstones in northern Maine. Conglomerates, graywackes, quartzites, slates, and volcanic rocks are present in Nova Scotia and Newfoundland (Poole *et al.*, in Douglas, 1970, fig. VI-12, pp. 257, 258). Black graptolitic shale of the Polk Creek Formation occurs in the Ouachita Mountains of Arkansas and Oklahoma.

Latest Ordovician solitary rugose corals are found almost exclusively in carbonate rocks. They are most common in the Richmond Group, in carbonates of the continental margin, and in the uppermost Ordovician carbonate unit overlying the Maquoketa Group (Text-fig. 2). Solitary Rugosa are sparse in carbonate beds within the Maquoketa. They are associated with calcareous debris in the clastic sequences of northern Maine.

RICHMOND GROUP

Introduction

The Richmond Group forms a narrow carbonate belt that extends from the Nashville Dome in Tennessee along the Cincinnati Arch region of Kentucky, Indiana, and Ohio to northern Michigan and Manitoulin Island, Ontario (Text-fig. 2). It was deposited during Richmondian time at the margin of an epicontinental sea between the Queenston deltaic shales and Maquoketa marine shales. In general, the group comprises a regressive sequence including characteristic interbedded carbonate rocks and shales, carbonate units, and beds of abundant colonial corals and stromatoporoids. A Richmond Group fauna occurs in carbonate beds at the top of the Maquoketa in the Green Bay, Wisconsin, area. In the vicinity of Meaford, Streetsville, and Montréal in southern Ontario and Québec, the Rich-

mond lithology was overlapped by sediments of the prograding Queenston delta. An outlier including Richmond strata is present at Lake St. John, Québec.

The lower and upper boundaries of the Richmond Group (Winchell and Ulrich, 1897) and Richmondian Stage (Foerste, 1903) as presently recognized are shown in Text-figures 3 and 18. Although the Richmond Group is seldom lithologically distinct from the underlying Edenian-Maysvillian sequence, the term is retained herein for reference to the belt of Richmondian strata having a depositional history and fauna similar to that of the type sections in the Cincinnati Arch region.

Cincinnati Arch Region

Stratigraphy

Prior to 1960, stratigraphic subdivision of the Richmond Group in the Cincinnati Arch region (Text-fig. 2, area No. 1) was based on faunal zonation, and resulted in recognition of the Arnheim, Waynesville, Liberty, Whitewater, and Elkhorn Formations. The history of development of this classification was summarized by Weiss and Norman (1960). These divisions are now viewed as invalid rock-stratigraphic units, but have commonly been used in the sense of time-stratigraphic subdivisions of the Richmondian Stage (Kohut and Sweet, 1968, pp. 1456, 1457). They are used as such herein, and the names are placed in quotation marks to emphasize their informal nature (Text-fig. 1).

Since publication of the Code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature, 1961), attempts have been made to subdivide the Cincinnati sequence lithostratigraphically. In Indiana, this has been done by Fox (1962), Brown and Lineback (1966), and Gray (1972). Gray's (1972, table 1) subdivision of the upper Cincinnati into the Dillsboro Formation and Whitewater Formation, including the Saluda Member, is followed herein. Richmondian strata on the northeastern side of the Cincinnati Arch region are lithologically similar to those in Indiana, and Gray's classification is herein extended into Ohio. In Kentucky, the Richmond Group has been lithostratigraphically subdivided through the mapping program of the U.S. Geological Survey in cooperation with the Kentucky Geological Survey. These units have been described on U.S. Geological Survey Quadrangle Maps, and were discussed by Weir, Greene, and Simmons (1965), Peck (1966), Simmons and Oliver (1967), and Peterson (1970).

The Richmond Group of the Cincinnati Arch region is overlain by the middle Llandovery (Lower Silurian) Brassfield Formation. The contact is generally discon-

formable, but a paraconformity exists in the eastern part of the region (Gray and Boucot, 1972, p. 1301).

Southeast.—On the southeastern side of the Cincinnati Arch region (Text-fig. 3, sections 6–9), the Ashlock Formation, which is partly Maysvillian in age, is overlain by the Drakes Formation. The Terrill Member of the Ashlock Formation consists primarily of evenly-laminated, greenish gray, dolomitic mudstone. Ripple marks and mud cracks are common in some areas. Bryozoans and brachiopods are locally sparse at the base, and small stromatolites are occasionally found near the top of the member (Weir, Greene, and Simmons, 1965, p. 13). The unit is silty in the vicinity of sections 7 and 8, and the amount of mud increases to the north at section 9. The basal portion of the overlying Reba Member of the Ashlock Formation consists of gray, micritic limestone with sparse ostracodes. Cylindrical burrows oriented perpendicular to bedding planes are abundant at southern localities. The upper portion is wavy-bedded, silty, medium-grained limestone that generally becomes argillaceous toward the top and contains abundant bryozoans and brachiopods (Weir, Greene, and Simmons, 1965, p. 13).

The Rowland Member forms the lower part of the overlying Drakes Formation. It consists of laminated, greenish gray, dolomitic or limy, silty mudstone. The unit becomes less silty but increasingly dolomitic and argillaceous to the north. Some bedding surfaces have ripple marks or mud cracks. Megafossils are absent to rare (Weir, Greene, and Simmons, 1965, p. 17). The uppermost Richmondian unit is the Preachersville Member of the Drakes Formation. It is similar to the Rowland Member, but contains argillaceous dolomite and dolomitic limestone in resistant beds that are commonly thicker near the base of the member and increase in abundance northward. Poorly preserved bryozoans and sparse brachiopods occur in some strata (Weir, Greene, and Simmons, 1965, p. 18). The Otter Creek coral bed is locally present at the base of the Preachersville Member in the vicinity of sections 6 and 7 (Simmons and Oliver, 1967). It is usually less than 1 m thick, and consists of gray, generally medium-grained, argillaceous limestone with abundant colonial corals of the genera *Calapoecia*, *Foerstephyllum*, and *Tetradium*. Also common are solitary corals, cylindrical stromatoporoids, and brachiopods.

Southwest.—On the southwestern side of the Cincinnati Arch region (Text-fig. 3, sections 3, 4), the Grant Lake Limestone is overlain by the Drakes Formation. The type Grant Lake on the eastern side of the Cincinnati Arch is Maysvillian in age (Peck, 1966, pp. 14, 16), but on the southwestern side it extends

into the Richmondian. The unit consists of irregularly-bedded, silty and argillaceous, gray, fossiliferous limestone, and shale in discontinuous beds and partings. Thick intervals of cross-bedded calcarenite occur locally. Brachiopods and bryozoans are abundant, especially in the limestone. To the south, the portion of Grant Lake Limestone at the base of the Richmondian grades into the Gilbert Member of the Ashlock Formation (Weir, Greene, and Simmons, 1965, p. 12). This member, in the vicinity of section 4, consists of evenly- to wavy-bedded, gray, fossiliferous limestone with gray shale partings and interbeds. It contains brachiopods and gastropods, with stromatoporoids near the top.

The Rowland Member at the base of the Drakes Formation is similar to the Rowland Member on the southeastern side of the arch, but is more calcareous and fossiliferous. The overlying Bardstown Member consists of gray, silty and argillaceous limestone in discontinuous and lenticular beds, with sparse to abundant fossils and fossil fragments (Peterson, 1970). Brachiopods, bryozoans, solitary corals, and molluscs are common. The colonial corals *Tetradium*, *Foerste-phyllum*, *Favistina*, and *Calapoecia* form prominent biostromes. The Saluda Dolomite Member is present at the top of the Drakes Formation. At its base, the dolomite is thinly-bedded, calcitic, silty, and argillaceous. Above this, it appears massive in outcrop and is generally unfossiliferous. In the upper part, it is locally finely-laminated and burrowed. At the top of the member, limestone or dolomite and shale are preserved in some areas, and locally contain the colonial coral *Tetradium*, or ostracodes and gastropods.

East.—On the eastern side of the Cincinnati Arch region (Text-fig. 3, sections 1, 10), the Richmond Group comprises the Bull Fork Formation and the overlying Drakes Formation. The Bull Fork consists of alternating shale and limestone. The gray shale content increases from about 20 percent at the base to about 80 percent near the top of the unit. The generally fossiliferous limestone forms even to wavy and irregular strata, some of which are ripple-marked. Beds of sparsely fossiliferous micritic limestone with locally common ostracodes increase in abundance southward, whereas evenly-bedded to cross-bedded calcarenite is more common northward. Brachiopods and bryozoans are the most abundant fossils, but corals, trilobites, molluscs, crinoids, and ostracodes are common locally. In the vicinity of section 1, a solitary coral bed is present near the middle of the formation (Peck, 1966, pp. 16–22). The Sunset Member is recognized at the base of the Bull Fork Formation in the vicinity of section 10. The member is predominantly argillaceous to

silty limestone, with the remainder being gray shale. Brachiopods are sometimes found near the base, and stromatoporoids are locally present, especially near the top.

Overlying the Bull Fork, the Drakes Formation comprises a northern extension of the upper part of the Preachersville Member. It consists of calcareous to dolomitic mudstone with minor sparsely fossiliferous dolomite and limestone interbeds and lenses. The mudstone is generally grayish green, but is locally reddish purple near the top, as at locality 1c.

West.—On the western side of the Cincinnati Arch region (Text-fig. 3, section 2), the Bull Fork Formation intertongues with the upper Grant Lake Limestone of the southwest. In the vicinity of section 2, the Richmond Group comprises the upper part of the Bull Fork Formation and the overlying Drakes Formation. Bull Fork strata here and at the type area on the eastern side of the arch are lithologically similar. The Rowland Member at the base of the Drakes Formation consists of argillaceous, micritic limestone in even to nodular beds up to 1 m thick, with mudstone interbeds. The member is not dolomitic, as it is to the south. Colonial corals are abundant in local biostromes, and brachiopods and bryozoans are scattered in the unit. The Marble Hill bed of this area is included in the Rowland Member and comprises gastropodal and echinodermal calcarenite (Swadley, 1980). The overlying Bardstown Member consists of fossiliferous limestone in thin, even to irregular beds, with gray shale interbeds. Brachiopods and bryozoans are abundant, together with solitary corals, molluscs, crinoids, and trilobites. The proportion of shale is greater than that to the south. The Bardstown thickens immediately north of section 2 where the Rowland Member pinches out, and is indistinguishable from the underlying Bull Fork Formation. The overlying Saluda Dolomite Member of the Drakes Formation is the uppermost Richmondian unit in this area. In the basal portion, thin beds of argillaceous limestone containing brachiopods and bryozoans occur in argillaceous dolomite. The upper part of the member is generally unfossiliferous, thickly-bedded dolomite. A thin bed of fossiliferous limestone is rarely present at the top.

Northwest.—On the northwestern side of the Cincinnati Arch region in Indiana (Text-fig. 3, sections 11, 5, 12), the Maysvillian to Richmondian Dillsboro Formation is overlain by the upper Richmondian White-water Formation, which includes the Saluda Member. The Dillsboro Formation (equivalent to the Tanners Creek Formation of Fox, 1962, pp. 626–628) comprises thin beds of argillaceous limestone alternating with calcareous shale. Fossils are common to abundant,

and include bryozoans, brachiopods, and trilobites. Solitary corals are common in the upper Dillsboro at southern localities such as section 11 and the Clifty Power Plant section of Hattin *et al.* (1961, pp. 328–331). Limestone beds are much more fossiliferous than the shales. The biostratigraphy was discussed by Fox (1962). Faunal distribution and abundance has been shown for interval 5a (Hay, 1977, fig. I-10) and intervals 5b-6 to 9 (Hay, 1977, fig. I-8, Liberty Formation) of section 5.

The overlying Whitewater Formation is composed predominantly of a variety of thin and often rubbly-bedded argillaceous limestones, with some shale and dolomite (Fox, 1962, p. 628; Brown and Lineback, 1966, p. 1022). Shale intervals occur toward the top of the formation at northern localities. Fossils, especially bryozoans, brachiopods, solitary corals, and molluscs, are abundant in the lower Whitewater Formation in the north. Faunal distribution and abundance has been shown for intervals 12a-1 to 9 of section 12 (Hay, 1977, fig. I-6) and intervals 5b-1 to 5 of section 5 (Hay, 1977, fig. I-8). The upper Whitewater is unfossiliferous to sparsely fossiliferous. Biostratigraphy of the formation was discussed by Fox (1962). The Saluda Member in Indiana is a northward-thinning wedge of dolomite, dolomitic limestone, and dolomitic mudstone with a colonial coral bed near its base (Brown and Lineback, 1966, pp. 1021, 1022). The Saluda is present at the base of the Whitewater Formation in the south (Clifty Power Plant section of Hattin *et al.*, 1961, pp. 328–331; section 11), and within the Whitewater to the north. The dolomite content decreases northward, and at section 5 near the northern limit of the member, the colonial corals are overlain by limestone that is commonly thickly-bedded. Except for the colonial coral bed, the Saluda Member contains very few fossils other than ostracodes.

Northeast.—The Richmond Group on the northeastern side of the Cincinnati Arch region in Ohio (Text-fig. 3, sections 13, 14) is lithologically similar to the group in Indiana, but shale is more abundant in the Whitewater Formation, and the Saluda Member is not present.

Depositional Environments

Previous Work.—Fox (1962) studied the composition, texture, and structure of the sedimentary rocks, and the contained biota of the Richmond Group in Indiana. He concluded that the Dillsboro Formation was deposited in a stable marine environment below effective wave base. He found evidence of shoaling with some subaerial exposure in the Whitewater For-

mation immediately below and above the Saluda Member, which formed in a lagoon that was periodically subaerially exposed. Another episode of shoaling occurred during later "Whitewater" time. Fox (1968), on the basis of the sparite-micrite ratio in limestones, interpreted the Dillsboro as a regressive sequence interrupted near its end by a transgressive phase.

Scotford (1965) studied the shale petrology of the "Waynesville" in the Cincinnati Arch region and found sand and silt dominant in the south, and clay more abundant to the north. Kohut and Sweet (1968) noted that the Richmond Group is more argillaceous toward the south and grades into shales and limestones northward, where they suggested deposition occurred in deeper water. They recognized southern and northern conodont faunas with distributions probably related to water depth.

Hatfield (1968) studied the lithostratigraphy and paleoecology of the lenticular Saluda Member on the western side of the Cincinnati Arch region in Indiana and Kentucky. The unit was deposited in a quiet, saline, very shallow to periodically subaerially exposed lagoon that was isolated by encompassing colonial coral-stromatoporoid banks. On the basis of lithology, Anstey and Fowler (1969) stated that water depth was at a maximum during "Arnheim-Waynesville" time, at a minimum during Saluda Member deposition, and of intermediate depth in the "Liberty" and "Whitewater". W. D. Martin (1975, 1977) studied the composition, texture, structure, and biota of Richmond Group limestones in Indiana and Ohio. He concluded that the Dillsboro Formation was deposited in a shallow, generally low energy, offshore environment. Following Saluda deposition, the Whitewater Formation formed in more normal marine conditions. A slight initial increase in water depth was followed by a slow decrease, resulting in offshore through nearshore and finally periodically subaerial environments.

Hay (1977) discussed the Richmondian lithofacies sequence in Indiana. A regressive event at the end of "Arnheim" deposition may be marked by an unconformity. The transgression that followed culminated in the "late Waynesville-early Liberty", and the final regression with some oscillation occurred during the "late Liberty-Whitewater-Elkhorn" interval. The stratigraphic ranges of a small number of conodonts characteristic of the European fauna extend into the Arnheim (Kohut and Sweet, 1968). This fauna is more conspicuously represented in pre-Maysvillian Ordovician strata of the Cincinnati Arch region. During late "Waynesville" time, an upper Richmond conodont fauna entered the region and reached its climax in the "Whitewater".

Swadley (1980) examined the Marble Hill bed on the west side of the Cincinnati Arch region and concluded that it represents an offshore bar-tidal channel complex along the northern edge of a shallow marine platform on which the Rowland Member of the Drakes Formation was deposited. Sediments of the Bull Fork Formation accumulated on an open marine shelf to the north.

Present Study.—The nature of the Richmond Group around the entire Cincinnati Arch region is seen in the 14 composite stratigraphic sections examined herein (Text-fig. 3). The following characteristics are demonstrated:

1. The group thickens from about 45 m in the south to about 90 m in the north on both eastern and western sides of the region.
2. The argillaceous, silty, and dolomitic sediments of the south grade northward into interbedded shales and limestones.
3. Sections on the eastern side contain more shale and dolomite than those on the west, where limestone is more common.
4. Fossils generally increase in abundance northward, and are more common on the western side than on the east.
5. On the eastern side of the region, dolomitic shale of the Preachersville Member occurs at the top of the Richmond Group, whereas the lenticular Saluda Dolomite Member is present at or near the top on the western side from section 5 southward.
6. Colonial coral biostromes occur on the southeastern side of the region in the Otter Creek coral bed, and are prominent on the western side particularly in association with the Saluda Member.

It is apparent from lithologies, thicknesses, and biota that the Richmondian epicontinental sea in this region became progressively deeper to the north, and depositional strike was oriented east-west. On the eastern side of the Cincinnati Arch region nearest the Queenston delta, marine environments were more restricted and terrigenous input was greater than to the west. Less restricted environments prevailed on the western side which faced the main body of the epicontinental sea, although in later Richmondian time the development of colonial coral banks resulted in Saluda deposition within a restricted lagoon.

In some areas, an early Richmondian regression appears to have been followed by a transgression. The top of the "Arnheim" in Indiana and the top of the Terrill Member of the Ashlock Formation in the southeastern part of the Cincinnati Arch region may mark

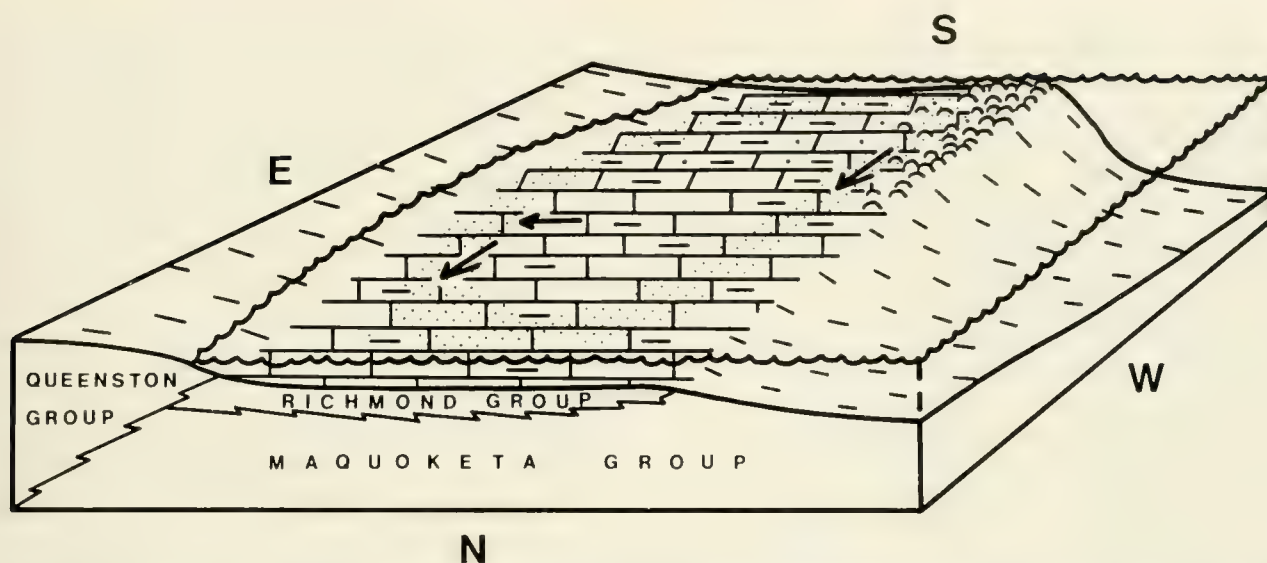
the end of this regression. Generally speaking, the Richmond Group as a whole represents a regressive sequence.

Cincinnati Arch

In Middle Silurian time the Cincinnati Arch was positive, relative to the subsiding Illinois Basin on the west and the Ohio Basin on the east. To the north, the Cincinnati Arch bifurcated into the Kankakee and Findlay Arches that marked the southern margin of the subsiding Michigan Basin (Shaver, 1974, fig. 6). These positive areas controlled the location and development of carbonate banks and reefs.

The history of studies dealing with the time of initial relative uplift of the Cincinnati Arch was summarized by Scotford (1964). Few authors have considered the structure to be older than Silurian. Scotford (1964) examined the problem on the basis of Ordovician shale petrology in the Cincinnati Arch region. In the "Waynesville", the measured parameters vary in a north-south rather than east-west direction, indicating that the axis of the arch was not a barrier to sedimentation. This variation would be expected with the east-west depositional strike and northward dip recognized herein. At the top of the Richmond Group, six of eight significant parameters differ on the eastern and western sides of the arch. Scotford (1964, p. 436) stated that these data "suggest the possibility that a weak barrier may have been developing along the axis of the arch, but its influence on the character of the shales on opposite sides of the axis was minor." He felt that the Cincinnati Arch should not be assigned an age earlier than Silurian.

If the Cincinnati Arch represents a broad, nearly level platform *without* a definite axis (Green, 1961), lithologies of this region *as a whole* should be compared with those to the east and west in order to determine its effects on sedimentation. During Richmondian time, deposition of the Richmond Group was confined to a narrow zone that extended from the positive Nashville Dome northward along the Cincinnati Arch region (Text-fig. 2). These deposits formed a carbonate belt separating the Queenston deltaic shales on the east and the Maquoketa marine shales on the west. Extensive colonial coral banks developed along the western margin of this belt, facing the main body of the epicontinental sea. The Cincinnati Arch appears to have been a subtle, broad platform sloping slightly to the north and influencing carbonate sedimentation and organic buildups during the Richmondian (Text-fig. 4). It was not until the Middle Silurian, when major basins subsided on either side, that the Cincinnati Arch became an obvious geologic feature.



Text-figure 4.—Middle Richmondian ("Liberty") paleogeography and lithofacies in a 90,000 km² area centered on the Cincinnati Arch region, as seen from the present northwest. Vertical scale greatly exaggerated. Richmond Group outcrop belt stippled. Colonial coral buildups shown in the southwestern Cincinnati Arch region. Arrows indicate paleocurrent directions. Based on data in Text-figures 2, 3, and 5, and Gray (1972).

Solitary Rugose Corals

Two species of solitary corals, *Grewingkia canadensis* (Billings, 1862) and *Streptelasma divaricans* (Nicholson, 1875b), are present in the Richmond Group of the Cincinnati Arch region. Their distribution and relative abundance are shown in Text-figure 3.

Grewingkia canadensis (Billings, 1862)

Stratigraphic Distribution.—*Grewingkia canadensis* is generally found within and on limestone beds containing common to abundant brachiopods and branching bryozoans. The earliest occurrence of this species at the base of the "Waynesville" in the vicinity of sections 11 and 2 on the western side of the Cincinnati Arch region and section 1 on the east suggests introduction during an early Richmondian transgression. The initial distribution along depositional strike about halfway between the deeper northern end and shallower, periodically subaerially exposed southern end of the region indicates preference for normal marine water in the intermediate depth range where calcium carbonate sediments accumulated and brachiopods and bryozoans thrived. The species dispersed to the north and south as favorable environmental conditions appeared elsewhere, and was most widely distributed during the "Liberty-early Whitewater". *G. canadensis* did not live in the restricted Saluda lagoon, or in very shallow environments associated with the final regression at the end of the Richmondian.

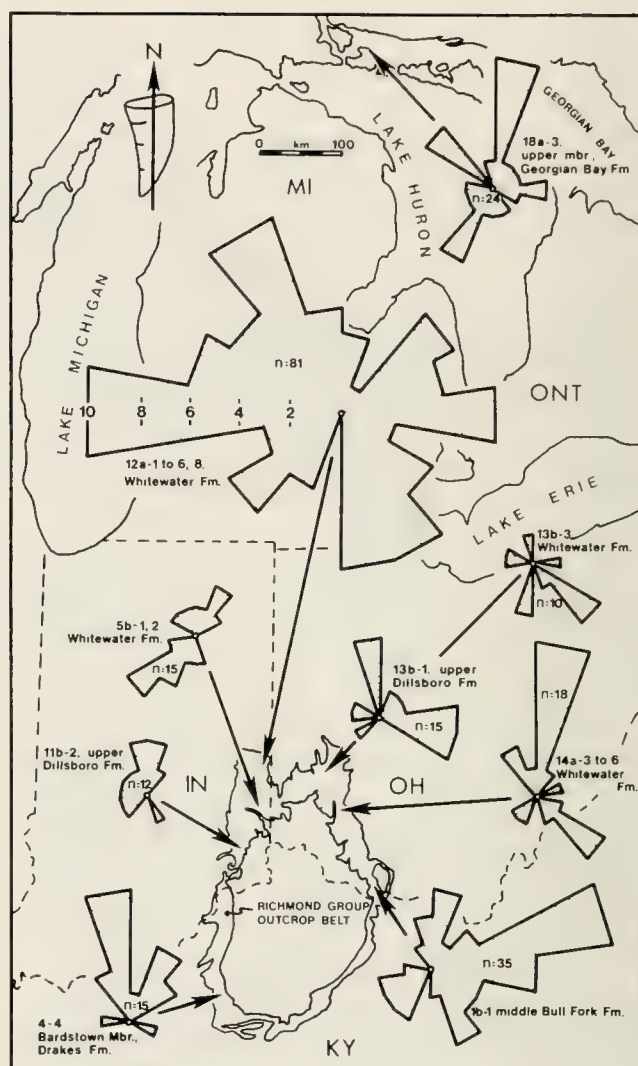
Orientation of Corals.—Growth lines, septal grooves, and interseptal ridges are rarely preserved on specimens of *Grewingkia canadensis*, and the outer portion of the stereozone generally is absent. Tips of the corals are almost always rounded, and calice rims of some were broken prior to deposition (Pl. 8, fig. 25, Pl. 9, fig. 10). Corals oriented with calices approximately horizontal and facing "up", presumably in life position (Wells, 1957), are extremely rare. Of more than 500 specimens collected, two from interval 5c-1 of section 5 (UCGM 45288) and one from interval 14b-1 of section 14 (UCGM 45465) were preserved in this way. All others were lying on their sides when buried (Pl. 3, fig. 13). Of 143 corals, 76 percent were oriented in the most stable position with an alar side facing "up" (*i.e.*, plane of curvature horizontal), and only 15 percent and 9 percent were deposited with the counter and cardinal sides "up", respectively. These features indicate that the corals were abraded and transported prior to final deposition and burial.

The directional orientation of corals lying on bedding surfaces was measured at seven sections in the Cincinnati Arch region (Text-fig. 5). The distributions suggest preferential orientation related to predominant current directions. A unidirectional distribution would be expected if corals were oriented with tips facing the current. A symmetrical distribution with peaks 180 degrees apart could be produced in an oscillating current if they were oriented as above. However, it could also develop if these cylindrical objects were rolled perpendicular to a unidirectional or oscillating current

with tips facing either way. A current from the south is suggested at section 4 and possibly section 11 on the western side of the Cincinnati Arch region. The distributions at sections 5 and 12 on the northwestern side of the region are somewhat bilaterally symmetrical. This could reflect oscillating southwest–northeast and southeast–northwest currents at sections 5 and 12, respectively, if orientation was parallel to these directions. If the corals were rolled perpendicularly, the currents may have been from the southeast and (or) northwest at section 5, and southwest and (or) northeast at section 12. On the northeastern side of the region at sections 13, 14, and 1, orientations suggest currents from the south and west. Unfortunately, few paleocurrent data from the Richmond Group of the Cincinnati Arch region are available for comparison. Bucher (1919, fig. 14h–k) presented a small number of pararipple strike directions. The predominant direction in Indiana is east–northeast, but the significance of this is uncertain because localities from which data were combined are widely separated. Strike directions in Oldham County, Kentucky, are predominantly east–west. This is consistent with solitary coral orientations at section 4. Strike directions in Adams County, Ohio, and Fleming County, Kentucky, are predominantly north–northwest and north–south, respectively. These trends are consistent with coral orientations at section 1. Potter and Pettijohn (1963, fig. 4-15) found that megaripples in limestones of the Cincinnati Series, including a few from the Richmondian Stage in the vicinity of section 1, commonly strike approximately north–south. The average cross-bedding direction is to the west, although directions in quadrants containing Richmondian strata are to the north, south, and east.

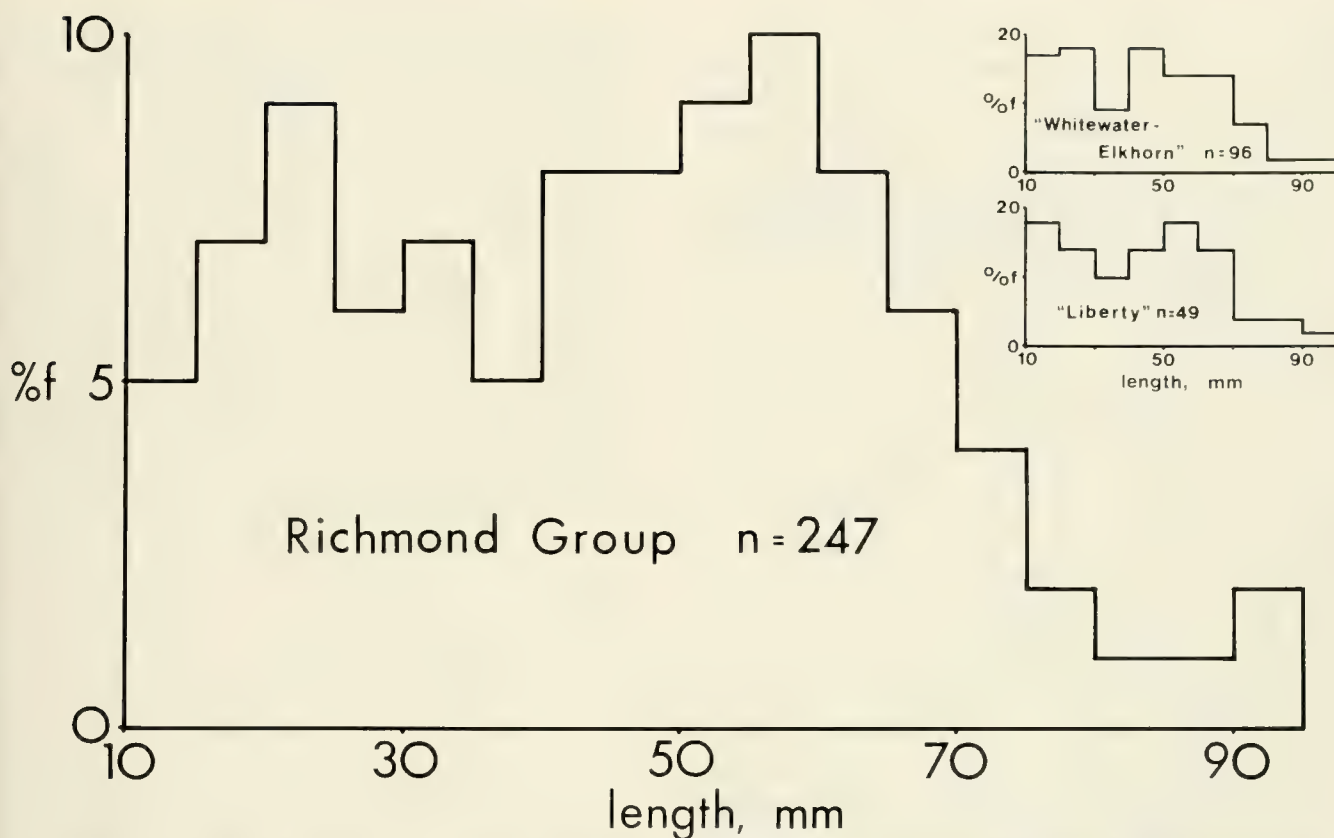
G. canadensis does not have a base of attachment, and clusters of individuals growing in lateral contact are rare (Pl. 9, fig. 17). The corals are ceratoid (Pl. 9, figs. 1, 2) to trochoid (Pl. 8, fig. 25) and are generally slightly curved in early to intermediate stages, becoming cylindrical and straight in late stages (Pl. 8, fig. 20, Pl. 9, fig. 2). They can be longer than 13 cm. This growth form suggests low energy, stable environmental conditions in which the corals slowly sank vertically into the sediment because of weight added during growth (Wells, 1957). They were overturned, abraded, and transported in higher energy conditions before final deposition.

Coral Size.—Length. The length-frequency histogram for *Grewingkia canadensis* in the Richmond Group of the Cincinnati Arch region is bimodal with peaks at 22.5 and 57.5 mm (Text-fig. 6). Similar distributions are observed at all stratigraphic positions



Text-figure 5.—Directional orientation of specimens of *Grewingkia canadensis* (Billings, 1862) in the Richmond Group (see Text-figs. 3, 18, for stratigraphic positions). Orientation convention shown using north arrow as an example. All frequency distributions plotted to the scale shown in largest rose diagram (upper center of figure). *n* = number of specimens.

and geographic locations within the region (Text-figs. 6, 7), and also in samples from Drummond Island, Michigan. The length-frequency histogram for the species cannot be understood completely because biologic factors such as birth rate, growth rate, and death rate are unknown. However, the bimodal distribution could be due to current sorting involving selective removal from an initial population of many individuals less than about 57.5 mm long and especially about 37.5 mm long (Text-fig. 7A). Changes in external form and degree of septal dilation during ontogeny determined shape, surface area, and weight, which would have affected the motion of corals in currents.



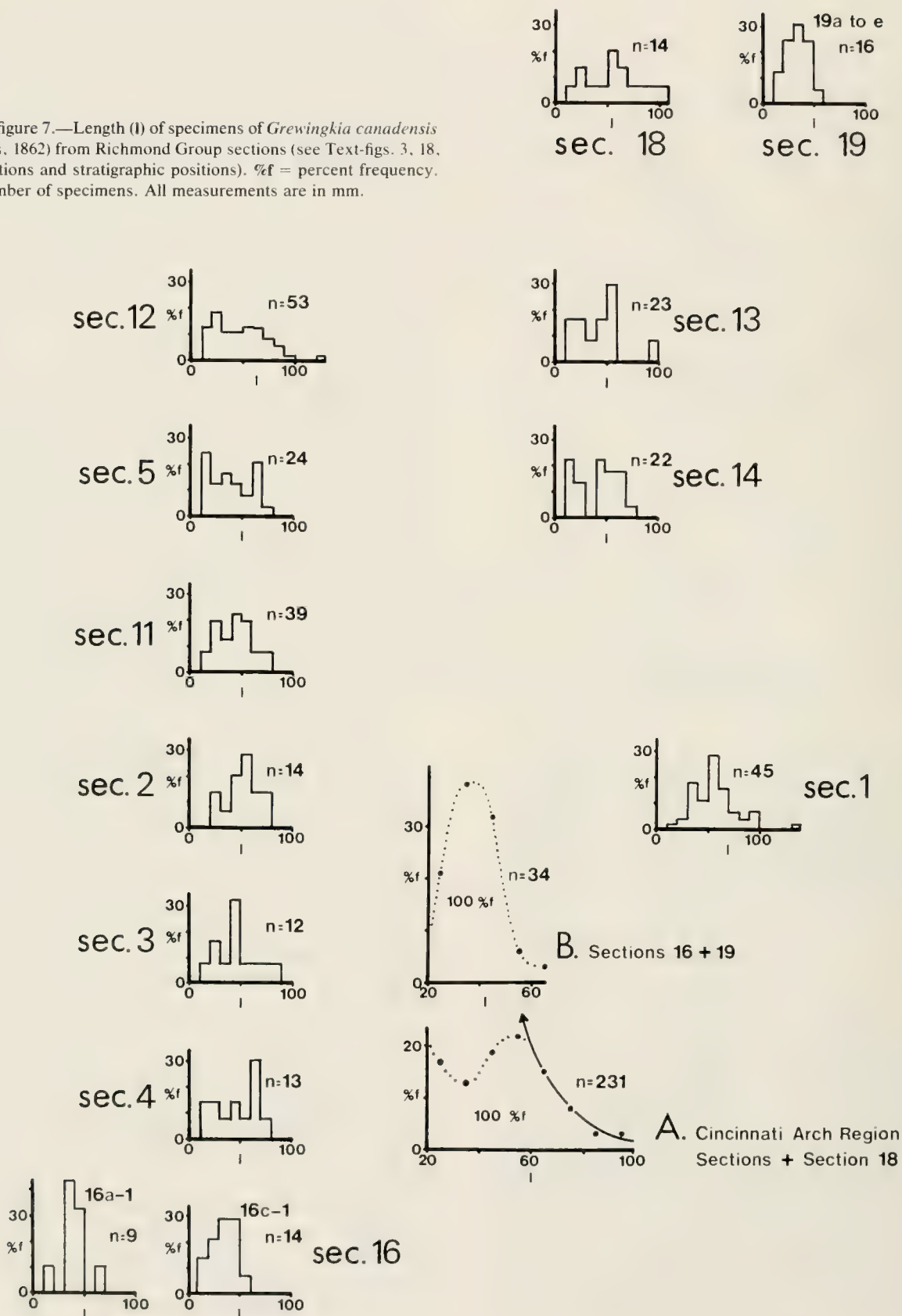
Text-figure 6.—Length of specimens of *Grewingkia canadensis* (Billings, 1862) from the Richmond Group and two intervals within it, Cincinnati Arch region. %f = percent frequency. n = number of specimens.

The length-frequency histograms for specimens of *G. canadensis* from stratigraphic intervals 16a-1 and 16c-1 in the Goodlettsville-Gallatin area of Tennessee, and stratigraphic intervals 19a to e at Manitoulin Island, Ontario, are unimodal with peaks at 35 mm (Text-fig. 7). These peaks correspond to the low frequency area of the bimodal distributions (Text-fig. 7A, B). The very low frequency at 60 mm coincides with the maximum length of corals thought to have been removed from an initial population. Corals deposited in these stratigraphic intervals may have been transported from elsewhere. Further evidence of extensive transport is discussed under "Goodlettsville-Gallatin Area, Tennessee", and "Manitoulin Island, Ontario". It is noteworthy that the unimodal distributions occur in near-shore areas at extremes of the species' geographic range. The rapidly decreasing frequencies below about 35 mm in these distributions may indicate that all corals removed from an initial population were not deposited together. The smallest size fractions could have been transported elsewhere, perhaps even closer to shore. A possible example of this phenomenon is discussed under "Streetsville, Ontario".

The bimodal length-frequency distributions for *G. canadensis* at localities in the Cincinnati Arch region are considered to be the result of current sorting. The similarity of these distributions geographically and stratigraphically indicates uniform conditions during periods of high energy. Predominant paleocurrent directions to the north and east suggest that corals removed from this region may have been deposited north of the present outcrop area and shoreward near the extremity of the Richmond Group to the east. If the corals removed by currents could be added to those left behind, it would be possible to reconstruct the length-frequency distribution of an initial *G. canadensis* population. A combination of Text-figure 7A and 7B suggests that the distribution may have been unimodal and positively skewed, following the solid curve in 7A. Such a distribution resembles that for specimens of *Streptelasma divaricans* (Nicholson, 1875b), which were buried in life position or following very little transport (Text-fig. 14).

Diameter. The diameter of specimens of *Grewingkia canadensis* was measured at a height between 45 and 55 mm above the tip (Text-fig. 8). At sections 2, 3, and

Text-figure 7.—Length (l) of specimens of *Grewingkia canadensis* (Billings, 1862) from Richmond Group sections (see Text-figs. 3, 18, for locations and stratigraphic positions). %f = percent frequency. n = number of specimens. All measurements are in mm.



4 in the southwestern Cincinnati Arch region, almost all corals are 33 to 40 mm in diameter. At the other sections considered herein, most have a diameter of 22 to 32 mm. The significance of this distribution is discussed under "Summary".

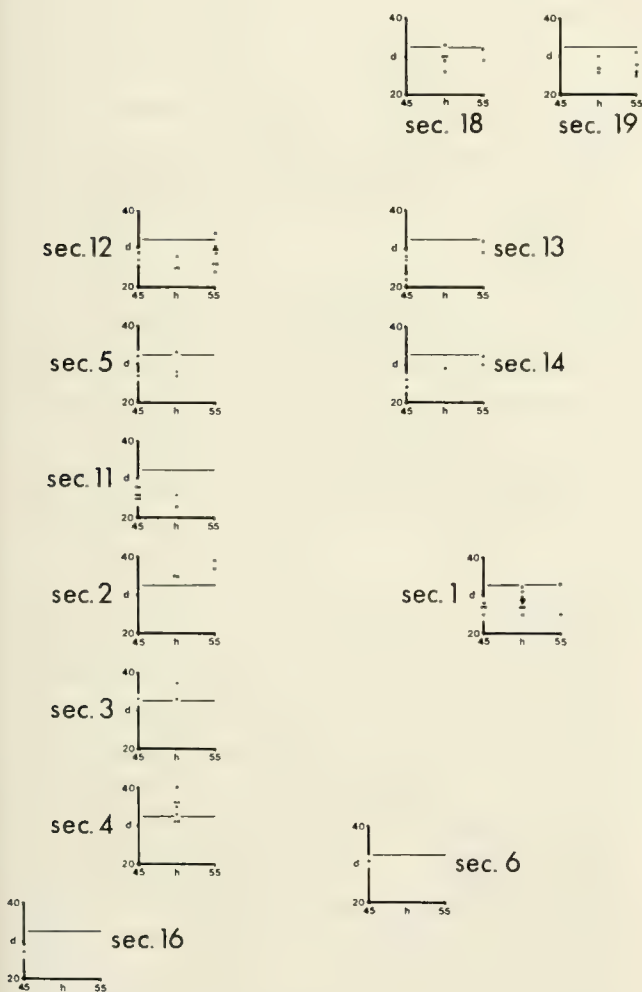
Epizoans.—Epizoic bryozoans, solitary *Rugosa* of *Streptelasma divaricans*, and colonial corals occur on *Grewingkia canadensis*. Bryozoans were noted on 54 percent of 529 corals collected in the Richmond Group of the Cincinnati Arch region. This percentage is approximately the same at all stratigraphic sections. Of 36 corals for which the side facing "up" at the time of final deposition on a bedding surface is known, 39 percent have bryozoans on or mostly on the "up" side, 36 percent on or mostly on the "down" side, 11 percent on lateral sides, and on 14 percent they are evenly distributed around the exterior. This uniform

distribution on the upper exposed and lower buried sides suggests that bryozoans became associated with the host corals before they were deposited, probably while they were in life position. Burial after deposition was apparently rapid, not allowing time for epizoans to colonize the exposed surface. A total of 513 bryozoan colonies or groups of colonies on 279 corals are located as follows: 37 percent on the counter side, 38 percent on an alar side, and 25 percent on the cardinal side. Bryozoans do not show strong preference for a particular side of the host solitary corals. This has also been observed in the Selkirk Member of the Red River Formation (upper Middle or Upper Ordovician), southern Manitoba (Elias, 1981, pp. 5, 6).

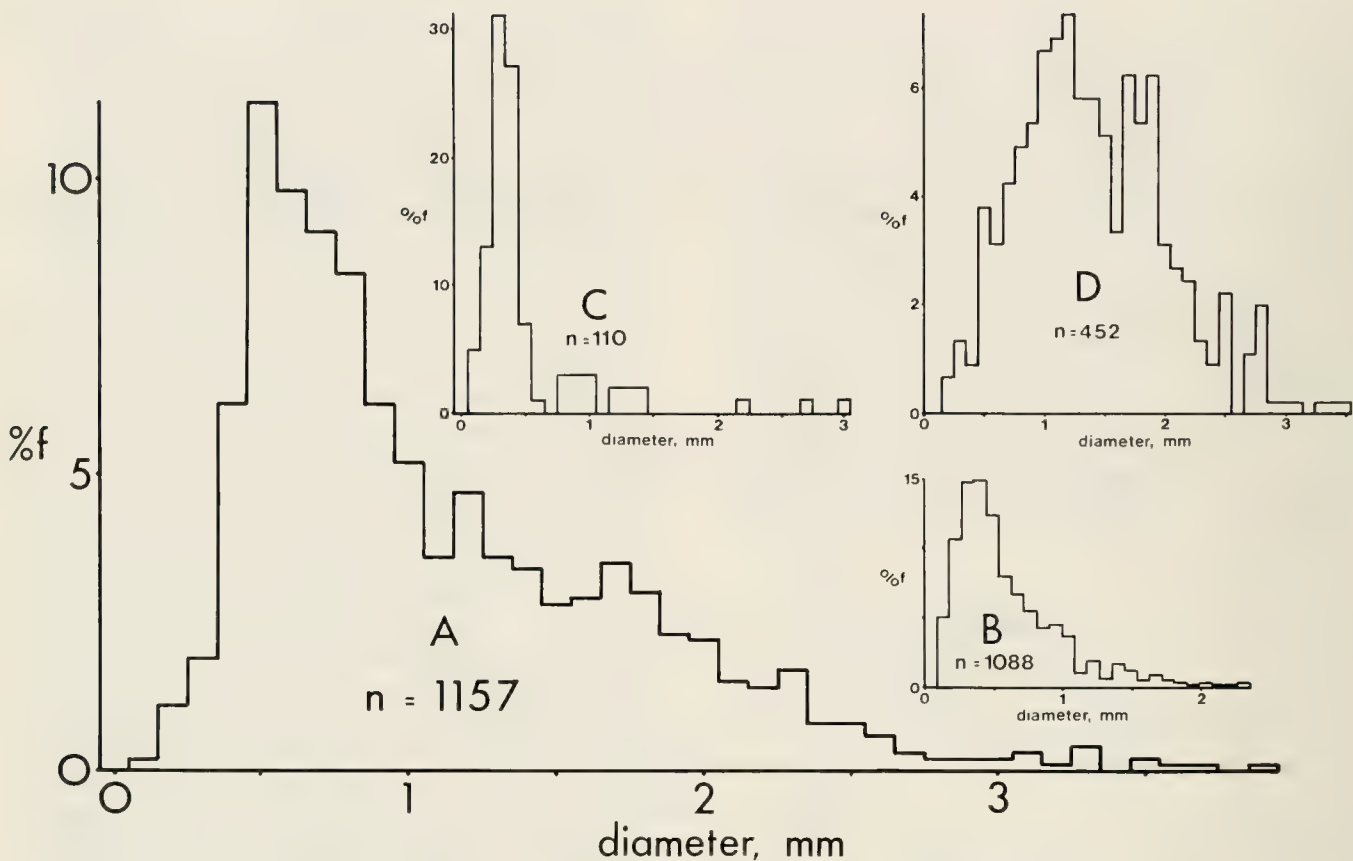
Epizoic corals assigned to *S. divaricans* are present on seven of 529 specimens of *G. canadensis*. These were found at intervals 5b-1 of section 5, 12a-1 of section 12, and 13b-1 of section 13, where both species are more abundant than usual (Text-fig. 3). Four epizoic corals are on the counter side of their host, two are on an alar side, and one is on the cardinal side. These epizoans may occur at any height above the host's tip. Two were worn down to the base of attachment before burial, suggesting that they lived on the coral before it was abraded during transportation. One that grew upright from the inner and outer rim of the host's calice probably became associated after death of the *G. canadensis* polyp but while the coral was still in life orientation. In some cases it is apparent that *S. divaricans* became epizoic on *G. canadensis* after transportation and deposition of the host (Pl. 3, fig. 13).

Only one of 529 specimens of *G. canadensis* (from interval 12a-2 of section 12) has an epizoic colonial coral attached to its counter side.

Borings.—Organisms that bored into corals of *Grewingkia canadensis* are annelids, bryozoans, and algae. Polychaete annelid borings, assigned to *Trypanites weisei* Mägdefrau (1932), are straight to slightly curved with a circular cross-section (Pl. 8, fig. 25, Pl. 9, fig. 10; Cameron, 1969, fig. 4g; Elias, 1980, p. 275). The diameter-frequency distribution of these borings in solitary corals from the entire Richmond Group, Cincinnati Arch region, is similar to that in brachiopods, bryozoans, and corals from the "Waynesville" near section 14 (Text-fig. 9A, B). The borings have an average diameter that is larger than those from the White Head Formation (Ashgill) near Percé, Québec, but smaller than those from the Selkirk Member of the Red River Formation (upper Middle or Upper Ordovician) in southern Manitoba (Text-fig. 9C, D). *T. weisei* borings were seen in 38 percent of 466 specimens of *G. canadensis* from the Cincinnati



Text-figure 8.—Diameter (d) of specimens of *Grewingkia canadensis* (Billings, 1862) from Richmond Group sections (see Text-figs. 3, 18, for locations). Each specimen is measured once at a height (h) between 45 and 55 mm. All measurements are in mm.



Text-figure 9.—Diameter of borings assigned to *Trypanites weisei* Mägdefrau (1932) in various Ordovician solitary rugose corals, brachiopods, and bryozoans. %f = percent frequency. n = number of borings.

A. Borings in 178 specimens of *Grewingkia canadensis* and two specimens of *Streptelasma divaricans* from the Richmond Group, Cincinnati Arch region.

B. Borings in six solitary corals, 45 specimens of the brachiopod *Hebertella insculpta*, and 21 bryozoans from "Waynesville" strata, Richmond Group, near Waynesville, Ohio (from Cameron, 1969, fig. 5c).

C. Borings in two specimens of *Helicelasma* and one specimen each of *Grewingkia* and *Lobocorallium* from the White Head Formation, Percé, Québec.

D. Borings in 108 specimens of *Grewingkia*, *Helicelasma*, and *Deiracorallium* from the Selkirk Member, Red River Formation, southern Manitoba (from Elias, 1976, fig. 17).

Arch region. This percentage is approximately the same at all stratigraphic sections. The location of 1124 borings in 174 corals is as follows: 48 percent in the counter side, 36 percent in an alar side, and 16 percent in the cardinal side. If all borings were produced after deposition of the hosts, most would be expected in an alar side, which usually faced "up". Predominance of *T. weisei* in the counter side must be due to preference of the boring organism when the coral was in life orientation. It is noteworthy that this preference is shown for slightly curved to straight corals of *G. canadensis* that were apparently oriented upright in the sediment, as well as for distinctly curved Selkirk Member corals that lay with the convex cardinal side in the sediment and the concave counter side facing upward during life (Elias, 1980, p. 275, fig. 5). Of 26 specimens of *G.*

canadensis for which the side facing "up" on the bedding surface at the time of final deposition is known, 61 percent have borings in or mostly in the "up" side, 31 percent have them uniformly distributed around the coral, and in 8 percent they are in or mostly in the "down" side. This suggests that some boring occurred after deposition of the corals. Richards and Shabica (1969) found that borings in brachiopods of the "Arnheim-Waynesville" in the vicinity of section 5 were produced subsequent to deposition of the shells.

Borings of ctenostomate bryozoans occur in only three of the corals collected for this study. All are from the "Waynesville" at section 14. In one specimen (UCGM 45468 from interval 14b-1), they are present in the cardinal side, and in the other two (UCGM 45469 from interval 14b-1, UCGM 45470 from interval

14b-2) the bryozoans bored into all sides. Pohowsky (1978, pl. 1, fig. 1) illustrated borings of *Ropalonaria venosa* Ulrich (1879) in a solitary coral from "Waynesville" strata at Clarksville, Ohio.

Dictyoporus retiformis (Palmer and Palmer, 1977) appears as fine, dendritic to reticulate networks of channels on the substrate surface that radiate from a nearly central point of origin. This ichnospecies, known previously from a hardground in the Rivoli Member of the Middle Ordovician Galena Group in Iowa (Palmer and Palmer, 1977, p. 186, fig. 6), is present in the cardinal-alar side of a single specimen of *G. canadensis* from interval 11b-1 at section 11 (UCGM 45304). A different ichnospecies, *D. garsonensis* Elias (1980), occurs in solitary rugose corals of the Selkirk Member, Red River Formation, in southern Manitoba. These borings may be of algal origin (Elias, 1980, pp. 273, 274, figs. 1-3).

Microscopic algal borings in brachiopod shells from the Richmond Group of Ohio were described by Kobluk and Risk (1977). The pyrite that partially or entirely fills these borings was thought to be related to the activity of sulfur-reducing bacteria, and to have been precipitated around a nucleus such as a bacterium or algal cell, or within a structure such as an algal cell or organic membrane, soon after burial. Similar borings are very common in *G. canadensis*. They penetrate perpendicularly a short distance into the host and are generally filled with pyrite (Pl. 9, fig. 20). That they were produced by algae is beautifully demonstrated by the presence of modern algal borings in one specimen (Pl. 9, fig. 21). It was collected in a stream bed and the exposed surface was covered with a green algal film. Thin sections reveal very fine borings filled with green material that extend a short distance perpendicular to the coral exterior. Unlike the Ordovician algal borings, they penetrate micrite and secondary calcite crystals filling *Trypanites weisei* borings. They are similar in morphology but are finer than the Ordovician forms.

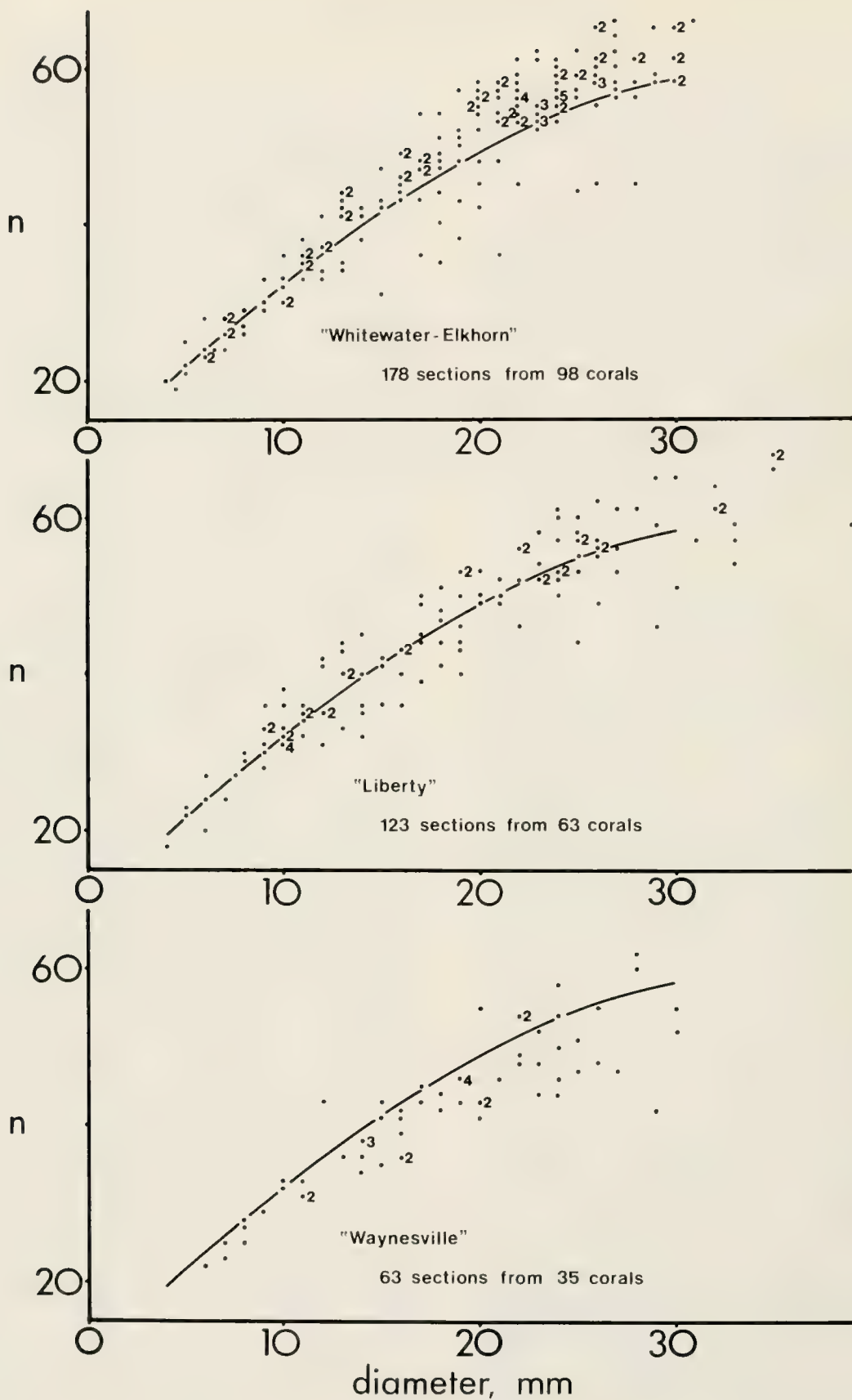
Almost all the Ordovician microscopic algal borings occur in the outer coral wall. Their position in 38 specimens is as follows: 55 percent have borings in all sides, 13 percent only in the counter side, 3 percent in a counter-alar side, 10.5 percent in an alar side, 8 percent in a cardinal-alar side, and 10.5 percent in the cardinal side. The algae show no preference for a particular location in the coral, and are generally present in all ontogenetic stages of the host. This, together with their common occurrence beneath epizoic bryozoans, suggests that boring took place very soon after secretion of the coral wall, while the host was in life position. In two specimens (UCGM 45212, 45226),

borings penetrate septa from interseptal chambers, and in one of the specimens (UCGM 45226) they also enter the coral from a *Trypanites weisei* boring. These algal borings were probably produced after death and decay of the polyp.

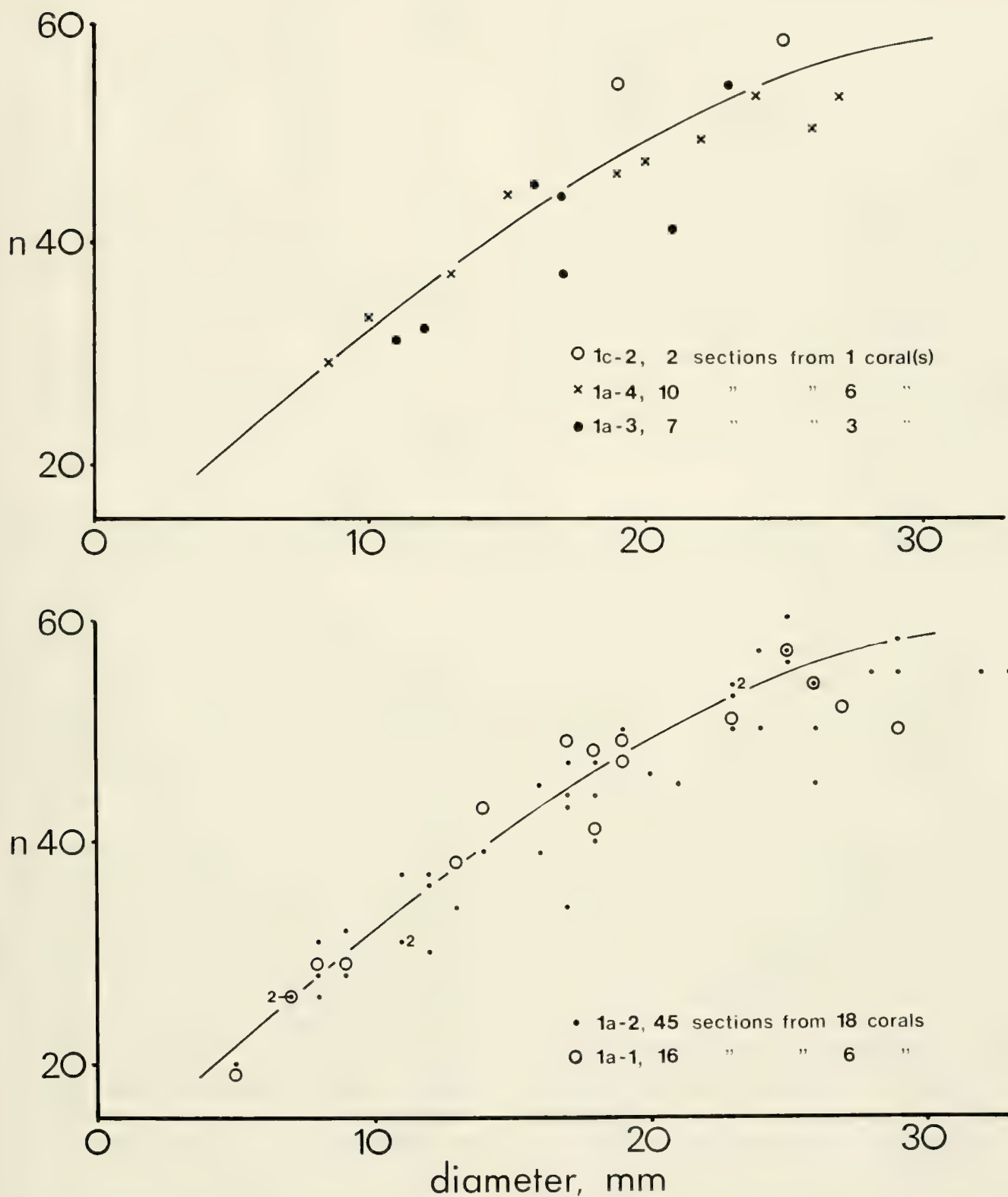
Microscopic algal borings are present in 93 percent of 57 corals from stratigraphic sections 1 to 5 and 10 to 14, for which thin sections were examined. The only stratigraphic sections at which all specimens do not have borings are 5, 12, and 13 in the northern part of the Cincinnati Arch region. The borings attain maximum diameter and length at section 4 in the southwest, and are finer and very short at sections 12, 13, and 14 in the north. Modern boring algae flourish in intertidal environments and may be abundant to a depth of about 20 to 25 m (Bromley, 1970, p. 54). The ubiquity and greater size of algal borings in the southern Cincinnati Arch region may reflect the southward decrease in water depth.

Intraspecific Variation.—Number of Septa. A general increase in the number of major septa at a particular coral diameter within *Grewingkia canadensis* of the Richmond Group in the Cincinnati Arch region is indicated by comparing values for specimens from "Waynesville", "Liberty", and "Whitewater-Elkhorn" strata (Text-fig. 10). At section 1 on the eastern side of the region, however, distributions through the entire group resemble those for "Liberty" strata elsewhere (Text-fig. 11). This is the only area in the Cincinnati Arch region where there are no major lithologic changes within the Richmond Group, except for an upward increase in shale that probably is related to progradation of the Queenston delta (Text-fig. 3). Environmental conditions apparently remained uniform during the Richmondian in the vicinity of section 1. The increase in number of septa elsewhere may have been the result of environmental change. Perhaps it was related to a decrease in water depth, as suggested by "Waynesville", "Liberty", and "Whitewater-Elkhorn" lithologies (see "Depositional Environments"). Differences in the number of septa at a particular diameter for samples from adjacent beds on Drummond Island, Michigan, and from geographically separated exposures of correlative strata on Manitoulin Island, Ontario, support the interpretation that this parameter was determined by environmental factors (see "Drummond Island, Michigan", and "Manitoulin Island, Ontario").

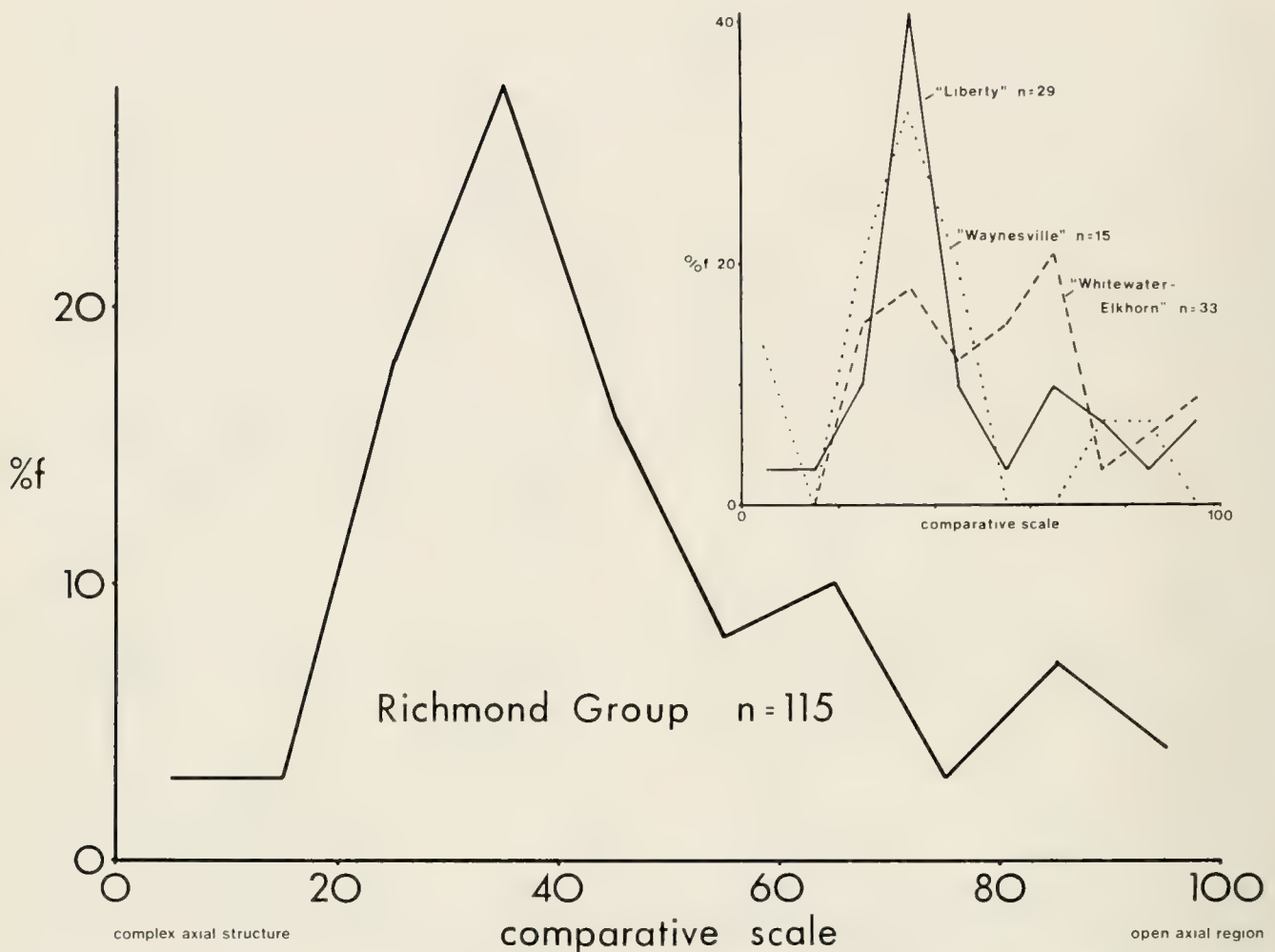
Axial Region. The nature of the axial region in late ontogenetic stages within *Grewingkia canadensis* is highly variable. There is complete gradation among individual corals from those in which a very complex axial structure with many septal lobes and lamellae is



Text-figure 10.—Relation between number of major septa (n) and coral diameter in *Grewingkia canadensis* (Billings, 1862) from three intervals within the Richmond Group, Cincinnati Arch region. Numbers indicate frequency of a point if greater than one. Curves represent averages for the entire Richmond Group, Cincinnati Arch region, as determined in Text-figure 33.



Text-figure 11.—Relation between number of major septa (n) and coral diameter in *Grewingkia canadensis* (Billings, 1862) from five intervals within the Richmond Group at section 1, Cincinnati Arch region (see Text-fig. 3 for stratigraphic positions). Numbers indicate frequency of a point if greater than one. Curves represent averages for the entire Richmond Group, Cincinnati Arch region, as determined in Text-figure 33.



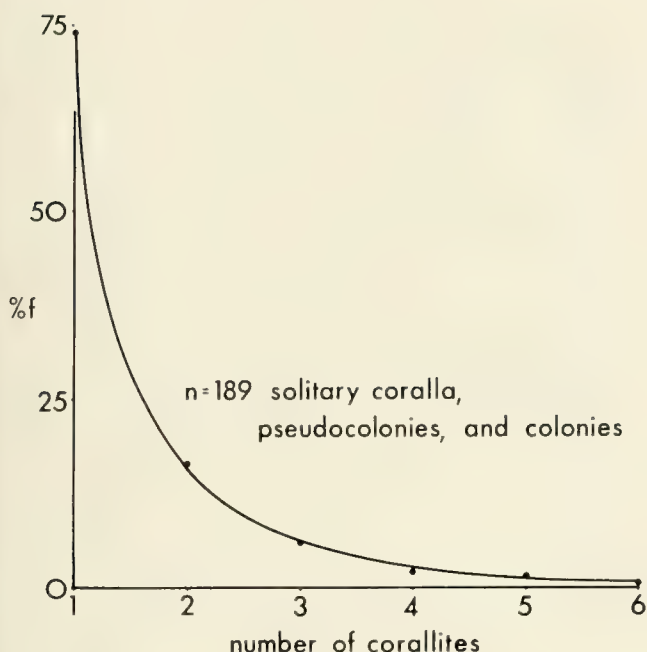
Text-figure 12.—Percent frequency (%f) of values on the axial region comparative scale (see Pl. 7, figs. 1–21) for specimens of *Grewingkia canadensis* (Billings, 1862) from the Richmond Group and three intervals within it, Cincinnati Arch region. *n* = number of specimens.

developed, to those having a simple axial structure with only a few septal lobes, to those in which major septa are withdrawn from the axis leaving an open axial region that lacks septal elements. To compare axial regions within this species, a scale was prepared using 21 specimens arbitrarily assigned values of 0, 5 . . . 100 on the basis of decreasing axial region complexity as determined by visual comparison (Pl. 7, figs. 1–21). Other corals were assigned values by visual comparison with this scale. The frequency distribution of values on the axial region comparative scale for *G. canadensis* from the entire Richmond Group in the Cincinnati Arch region has a peak at 35, indicating that most individuals have a moderately complex axial structure (Text-fig. 12). Although relatively few values are available for the "Waynesville", the frequency distribution has a peak at 35 with fairly low frequency below 25 and very low frequency above 45. The distribution for specimens from the "Liberty" has a pro-

nounced peak at 35, and frequency below 25 and above 45 is low. For the "Whitewater-Elkhorn", the greatest peak is at 65. There was apparently a trend in *G. canadensis* toward predominantly simpler axial regions, although the total range of variability remained approximately constant during the Richmondian. This trend, like the increase in number of septa, may have been related to decreasing water depth. Too few data are available to determine if frequency distributions of values on the axial region comparative scale throughout section 1 on the eastern side of the Cincinnati Arch region resemble those for "Liberty" strata elsewhere.

***Streptelasma divaricans* (Nicholson, 1875b)**

Stratigraphic Distribution.—The distribution of *Streptelasma divaricans* generally parallels that of *Grewingkia canadensis*, but the latter species is more abundant (Text-fig. 3).



Text-figure 13.—Percent frequency (%f) distribution showing number of corallites per corallum in *Streptelasma divaricans* (Nicholson, 1875b) from the Richmond Group, Cincinnati Arch region. n = number of specimens.

Orientation of Corals.—Whereas corals of *G. canadensis* formed a transported constituent within and on carbonate beds, *S. divaricans* was epifaunal on stabilized carbonate substrates during periods of non-deposition. Septal grooves and interseptal ridges are commonly preserved, indicating little abrasion (Pl. 1, figs. 20, 27, 30, 33; Pl. 2, fig. 11; Pl. 3, fig. 11s). Energy conditions remained low, and subsequent generally argillaceous sediments buried many corals in an upright position, apparently in life orientation (Pl. 3, fig. 3). Some were deposited on their sides and a few at sections 12 and 13 are oriented with calices facing “down”, indicating transportation before final burial.

Attachment sites centered on the cardinal side of 59 specimens of *S. divaricans* are as follows: 68 percent encrusting and branching bryozoans, 17 percent brachiopods (Pl. 3, figs. 8s, 9s, 10), 8 percent *Grewingkia canadensis* (Pl. 3, fig. 13), 5 percent colonial corals (Pl. 3, fig. 12), and 2 percent pelecypods. The larvae frequently attached to living bryozoan colonies, as demonstrated by upward growth of the host around these epizoids (Pl. 3, fig. 5s). The coral wall is sometimes absent at the site of attachment, and septa are in contact with the bryozoan (Pl. 3, fig. 7). The septa of *S. divaricans* are generally non-dilated, but in two specimens (UCGM 45018, 45128) they are moderately dilated where the corals are surrounded by bryozoans (Pl. 2, figs. 1–4). Dilation may have been a response

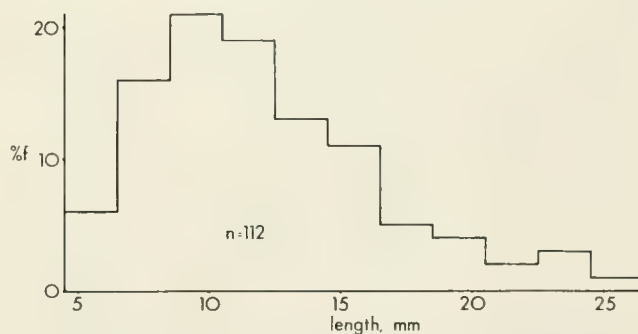
to stress. The location of *S. divaricans* on brachiopods is shown in Table 1. Richards (1972, p. 401) stated that

“many of the corals are located [on *Rhynchotrema dentatum* and *Lepidocyclus capax*] so that the polyp would have been bathed by the exhalant [sic] current. Perhaps the coral fed on food of a size or type systematically rejected by the brachiopod.”

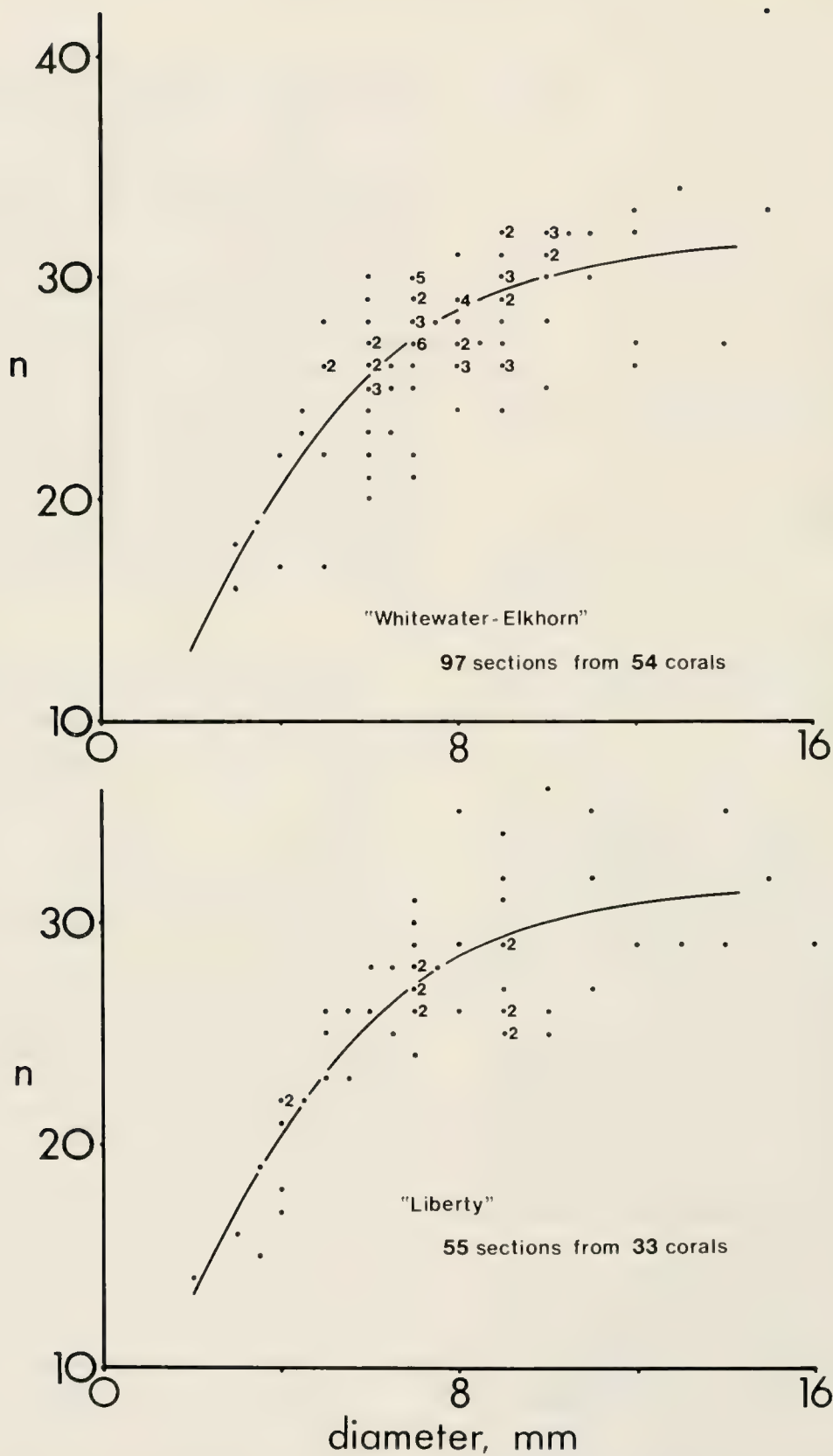
In interval 4-2 of section 4, *S. divaricans* occurs at the uppermost points on colonial corals, some of which had been overturned before colonization. The species apparently favored elevated positions on stabilized substrates in low energy conditions. *S. divaricans* was not found in the Bull Fork Formation at section 1 on the eastern side of the Cincinnati Arch region, although *G. canadensis* is common (Text-fig. 3). This is the only area where there are no major lithologic changes within the Richmond Group. Perhaps deposition was more continuous and uniform, not allowing the species an opportunity to colonize stabilized substrates.

Table 1.—Attachment sites of *Streptelasma divaricans* (Nicholson, 1875b) on brachiopods from the Richmond Group, Cincinnati Arch region [data from Richards (1972) unless specimen number is given].

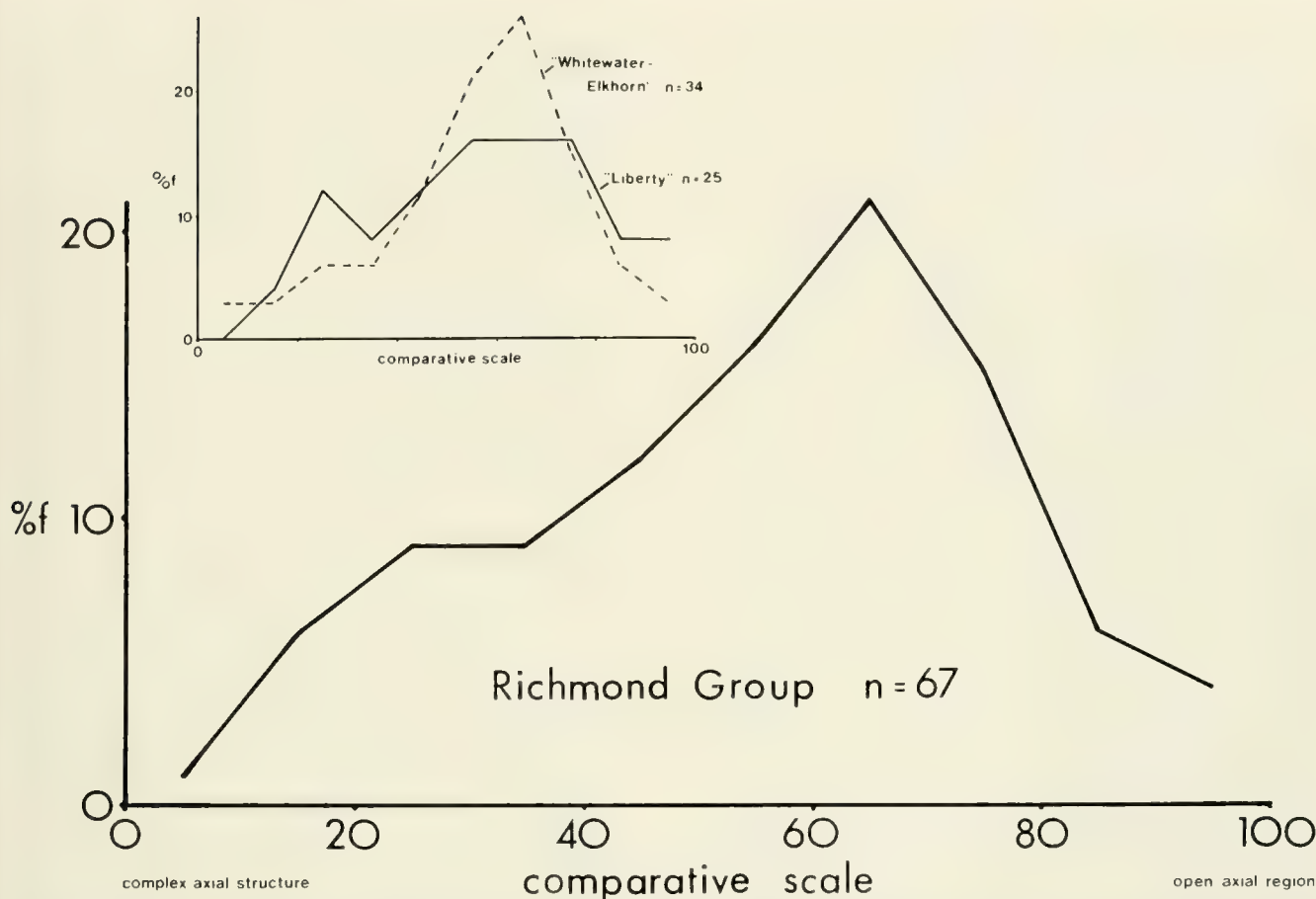
<i>Rhynchotrema dentatum</i>
9 on fold
5 off fold
<i>Lepidocyclus capax</i>
2 on brachial valve, anterior (UCGM 45066, USNM 40086)
8 on fold
<i>Leptaena richmondensis</i>
2 on geniculate part of pedicle valve
<i>Rafinesquina alternata</i>
1 on pedicle valve, anterior (USNM 135767)
<i>Holtehdahlina sulcata</i>
1 on anterior



Text-figure 14.—Length of specimens of *Streptelasma divaricans* (Nicholson, 1875b) from the Richmond Group, Cincinnati Arch region. %f = percent frequency. n = number of specimens.



Text-figure 15.—Relation between number of major septa (n) and coral diameter in *Streptelasma divaricans* (Nicholson, 1875b) from two intervals within the Richmond Group, Cincinnati Arch region. Numbers indicate frequency of a point if greater than one. Curves represent averages for the entire Richmond Group, Cincinnati Arch region, as determined in Text-figure 25.



Text-figure 16.—Percent frequency (%f) of values on the axial region comparative scale (see Pl. 1, figs. 1–19) for specimens of *Streptelasma divaricans* (Nicholson, 1875b) from the Richmond Group and two intervals within it, Cincinnati Arch region. *n* – number of specimens.

Of 189 specimens of *S. divaricans* collected in this study, 74 percent are solitary coralla and 26 percent include two or more corallites in lateral contact (Text-fig. 13; Pls. 1–3). The maximum number seen in a single group is 13. Most clusters apparently represent pseudocolonies, with true coloniality being rare (see “Systematic Paleontology”). This gregarious habit was probably due to selection of a favorable attachment site by more than one larva.

Coral Size.—The length-frequency histogram for *Streptelasma divaricans* in the Richmond Group of the Cincinnati Arch region is shown in Text-figure 14. This unimodal, positively skewed distribution probably reflects the population because many corals were preserved in life position and few show signs of extensive transport.

The longest corals occur at section 4 on the southwestern side of the Cincinnati Arch region. The significance of this is discussed under “Summary”.

Epizoans.—Epizoid organisms are very rare on *Streptelasma divaricans*, probably because of small coral size. Bryozoans are present on several larger

specimens at intervals 4-3 and 4-5 of section 4, and interval 12a-9 of section 12.

Borings.—Borings assigned to *Trypanites weisei* were seen in only two specimens of *Streptelasma divaricans* from interval 4-5 of stratigraphic section 4. Microscopic algal borings are present in 71 percent of 45 specimens from the Cincinnati Arch region for which thin sections were examined. Corals without algal borings are not restricted to the northern part of the region, as in *Grewingkia canadensis*. However, the borings are best developed south of stratigraphic sections 12, 13, and 14, possibly reflecting the southward decrease in water depth. The lower frequency of borings in *S. divaricans* than in *G. canadensis* may be related to the smaller coral size and the fact that the coral wall was frequently surrounded and protected by living host bryozoans.

Intraspecific Variation.—The number of major septa at a particular diameter is highly variable within *Streptelasma divaricans* of the Richmond Group, Cincinnati Arch region. Unlike *Grewingkia canadensis* (see Text-fig. 10), there is no marked difference in

values for corals from "Liberty" and "Whitewater-Elkhorn" strata (Text-fig. 15).

The nature of the axial region in late ontogenetic stages within *S. divaricans* is highly variable. There is complete gradation among individual corals from those in which a moderately complex axial structure of septal lobes and lamellae is developed, to those with a simple axial structure of only a few septal lobes, to those having major septa that extend to the axis without forming an axial structure, to those in which major septa are withdrawn from the axis leaving an open axial region lacking septal elements. To compare axial regions within this species, a comparative scale similar to that for *G. canadensis* was prepared, using 19 specimens assigned values of 5, 10 . . . 95 on the basis of decreasing axial region complexity (Pl. 1, figs. 1-19). Other corals were assigned values by comparison with this scale. The frequency distribution of values on the axial region comparative scale for *S. divaricans* from the Richmond Group in the Cincinnati Arch region has a peak at 65, indicating that most individuals have major septa extending to the axis without forming an axial structure (Text-fig. 16). The frequency distribution for specimens from the "Liberty" has a broad peak centered about the value 65. For the overlying "Whitewater-Elkhorn", a sharp peak is present at 65 and frequency below 40 is lower than in the "Liberty" distribution. As in *G. canadensis*, there was apparently a trend toward predominantly simpler axial regions, although the total range of variability remained approximately constant through the Richmondian. The axial regions of corallites within pseudocolonies and colonies are the same or similar in complexity. In pseudocolonies, this could reflect the similar environment they shared. Similarity within colonies could have been environmentally or genetically controlled. If the trend toward predominantly simpler axial regions was a response to environmental change, it may have been related to decreasing water depth, as previously discussed for *G. canadensis*.

Summary

In general, the Richmond Group of the Cincinnati Arch region represents a regressive sequence, possibly following a transgressive event in early Richmondian time. The argillaceous, silty, and dolomitic sedimentary rocks of the south grade northward into interbedded shales and limestones. Water depth became progressively greater northward, and depositional strike was oriented east-west. On the eastern side of the region nearest the Queenston delta, marine environments were more restricted and terrigenous in-

put was greater than on the western side, which faced the main body of the epicontinental sea. In these less restricted environments, extensive development of colonial coral banks temporarily produced a restricted lagoon in later Richmondian time. On the southwestern side of the Cincinnati Arch region, algal borings were best developed, colonial coral biostromes were most prominent (Browne, 1964, p. 389), and *Grewingkia canadensis* and *Streptelasma divaricans* attained their greatest diameter and length, respectively. This shallow, open shelf edge of the Richmond Group carbonate belt must have been an area of high productivity that was especially favorable for corals. The Cincinnati Arch was probably a subtle, broad platform sloping slightly to the north and influencing carbonate sedimentation and organic buildups during the Richmondian.

Grewingkia canadensis (Billings, 1862) and *Streptelasma divaricans* (Nicholson, 1875b) are the only solitary rugose corals known from the Cincinnati Series of the Cincinnati Arch region. They first appeared at the base of the "Waynesville" in the Richmond Group, suggesting introduction during an early Richmondian transgression. Both species have a similar stratigraphic distribution, and favored normal marine waters of intermediate depth where calcium carbonate sediments accumulated and brachiopods and bryozoans thrived. *G. canadensis* probably lived in stable, low energy environments, but the corals were transported in higher energy conditions before final deposition and rapid burial. Many of those less than about 60 mm and especially about 35 mm long were removed from the region. Whereas specimens of *G. canadensis* formed a clastic constituent within and on carbonate beds, *S. divaricans* was epifaunal on stabilized carbonate substrates during periods of non-deposition. The larvae commonly attached to elevated areas, especially on bryozoans. Energy conditions remained low, and subsequent generally argillaceous sediments often buried the corals in life position. In both *G. canadensis* and *S. divaricans* there was a trend toward predominantly simpler axial regions, although the total range of variability remained approximately constant. The average number of septa in *G. canadensis* generally increased during Richmondian time, but remained constant in the vicinity of section 1 on the eastern side of the Cincinnati Arch region where environmental conditions were apparently relatively uniform. These trends may have been related to decreasing water depth. During the final regression of the epicontinental sea at the end of the Richmondian, *G. canadensis* and *S. divaricans* became extinct.

Burkesville, Kentucky

In the vicinity of Burkesville (Text-fig. 2, area No. 2), the Richmond Group is represented by the 6 to 40 m thick Cumberland Formation, a predominantly unfossiliferous, fine-grained dolomite (Text-fig. 3). The dolomite is generally massive, but burrows and very fine laminae (?stromatolites) are also present. The formation was probably deposited in restricted, very shallow marine environments. A thin unit of limestone with shale interbeds occurs locally near the base, and was termed the Burkesville limestone by Jillson (1951). Calcilutite with birdseye structures is present in this unit, as well as a few brachiopods, branching bryozoans, and gastropods. This unit probably represents a brief normal marine incursion. Jillson (1951, pp. 13, 14) listed a diverse fauna that pointed "rather conclusively to the Waynesville age of the Burkesville limestone." Near the top of the Cumberland Formation, local limestone lenses and shale interbeds are also present. At interval 15b of section 15, 1 m of limestone is overlain by 0.2 m of shale. The limestone contains some branching bryozoans, brachiopods, and gastropods, and probably represents a short, normal marine interval. Also present are fine laminae and limestone pebble conglomerate, suggesting deposition in very shallow marine to possibly subaerial conditions. Jillson (1953) described the Haggard limestone from an approximately correlative position in interval 15d of section 15. He listed a solitary coral, the colonial genera *Columnaria* (?=*Favistina*), *Calapoecia*, and *Tetradium*, as well as brachiopods, bryozoans, and a few other fossils that distinguish this limestone "indisputably as a correlative of the Liberty division of the Richmond" (Jillson, 1953, p. 9). All exposed bedrock seen at this stratigraphic position is unfossiliferous dolomite. Loose blocks of fossiliferous calcilutite and calcarenite containing brachiopods, bryozoans, and typical Richmond Group colonial corals were found. Solitary Rugosa were not seen, and the location and identity of the specimens Jillson assigned to *Streptelasma rusticum* remains unknown. The presence of "Liberty" strata about 10 m below the top of the Cumberland Formation suggests that little was removed by post-Richmondian-pre-Devonian erosion.

Foerste (1912a, p. 447) reported solitary and colonial corals, and stromatoporoids east of Burkesville in Wayne County, Kentucky. He stated that this section probably correlates with the basal "Liberty".

Goodlettsville-Gallatin Area, Tennessee

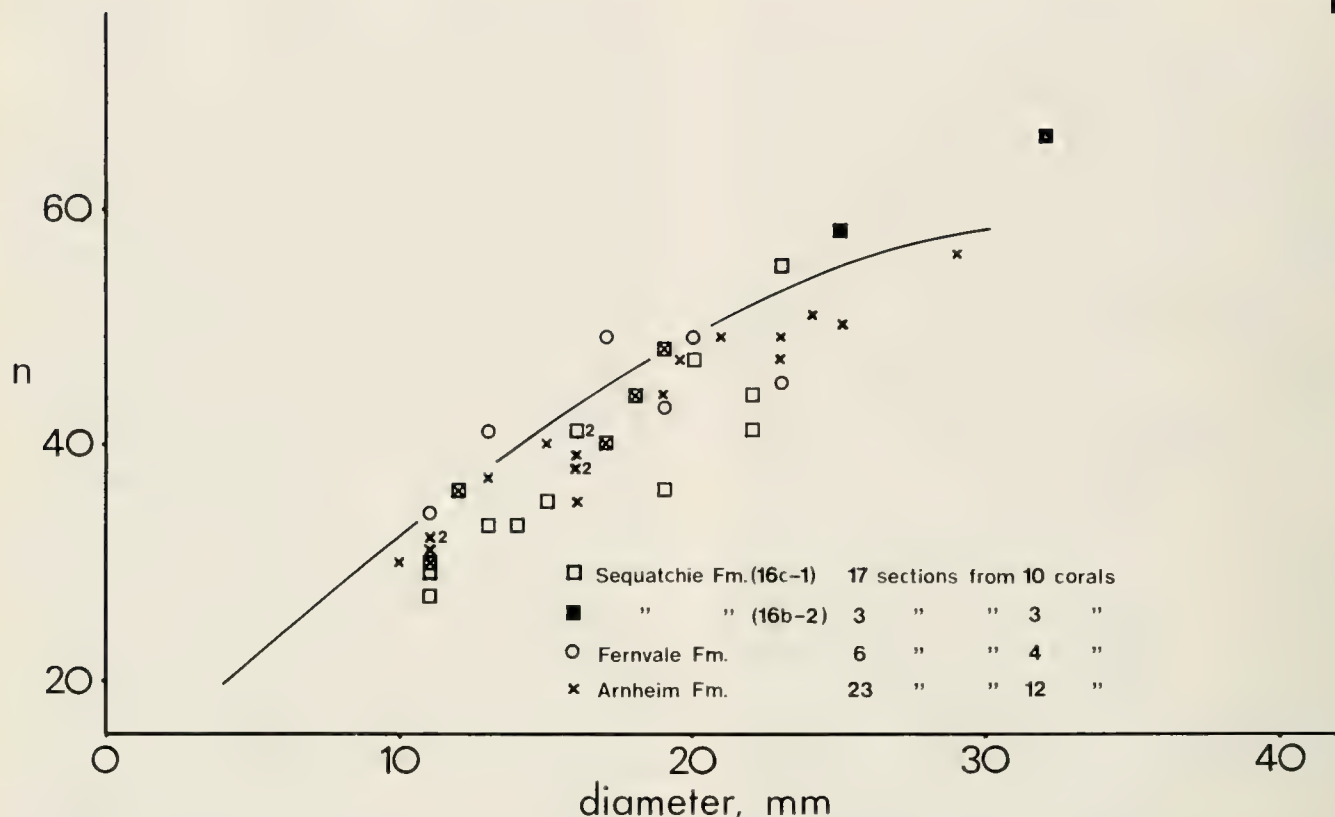
The Nashville Dome is known to have been periodically positive since the early Middle Ordovician (C.

W. Wilson, 1935). It was uplifted above sea level during the late Maysvillian, and remained so except locally until the Mississippian. Richmondian sediments of the Arnheim and overlying Fernvale Formations were deposited on the western and northern sides of the dome (Bassler, 1932, pp. 120–130; C. W. Wilson, 1949, pp. 201–207, 212–215). Clastic and carbonate sediments forming the Sequatchie Formation to the east (C. W. Wilson, 1949, pp. 209–211) intertongue at various positions in the Arnheim-Fernvale sequence on the north side of the Nashville Dome. The Richmond Group is overlain by the middle Llandovery (Lower Silurian) Brassfield Formation. At locality 16c, the basal Brassfield contains abundant solitary corals.

In the Goodlettsville-Gallatin area north of Nashville (Text-fig. 2, area No. 3), the Richmond Group varies from about 6 to 35 m in thickness (Text-fig. 3). The Arnheim Formation consists of rubbly-bedded argillaceous limestone with gray shale interbeds. The fauna was discussed by Foerste (1912a, pp. 446, 447), and listed by Bassler (1932, p. 124) and C. W. Wilson (1949, p. 207). Brachiopods are most abundant, and solitary corals are common. The Fernvale Formation consists of thicker and more evenly-bedded crinoidal calcarenites, and smaller amounts of finely-laminated calcilutite, with shale interbeds. Brachiopods and bryozoans are common, but solitary corals are rare. Fossils from the shale equivalent of the Fernvale were listed by C. W. Wilson (1949, p. 215). A western tongue of the Sequatchie Formation occurs at the top of the Richmond Group in the Goodlettsville-Gallatin area. It consists primarily of massive, unfossiliferous, argillaceous sandstone with some burrows and fine laminae. A few thin beds of calcilutite with birdseye structures and fine laminae are present locally. Several very thin lenses of fossils including common solitary corals and brachiopods occur in the sandstone.

The Richmondian sequence on the northern margin of the Nashville Dome appears to be regressive. The Arnheim was deposited in fairly low energy conditions, as indicated by the lithology (Howe, 1969, p. 1334). Fernvale sediments suggest a higher energy shoal (Howe, 1969, p. 1333). The lithology and sedimentary structures of the Sequatchie tongue indicate very shallow marine to possibly occasionally subaerial environments.

Bassler (1932, pp. 122, 124) noted that brachiopods in the Arnheim Formation of Tennessee are characteristic of "Arnheim" strata in Ohio, but some of these and other fossils are also typical of the "Waynesville". Howe (1969, pp. 1335, 1336) stated that the fauna of the Arnheim Formation indicates a Richmon-



Text-figure 17.—Relation between number of major septa (n) and coral diameter in *Grewingkia canadensis* (Billings, 1862) from four intervals in the Richmond Group, Goodlettsville-Gallatin area, Tennessee (see Text-fig. 3 for locations and stratigraphic positions). Numbers indicate frequency of a point if greater than one. Curve represents averages for the entire Richmond Group, Cincinnati Arch region (see Text-fig. 33).

dian age, but does not warrant precise correlation with the type Richmondian of the Cincinnati Arch region. On the basis of stratigraphic position, the Arnheim Formation of Tennessee may be equivalent to the "Arnheim-Waynesville". If the lower Arnheim Formation proves to be "Arnheim" in age, it contains the oldest solitary corals known in the Richmond Group. The stratigraphic position and predominance of limestone in the Fernvale Formation near Goodlettsville suggest correlation with the "Liberty". The upper tongue of the Sequatchie Formation may correspond to the "Whitewater-Elkhorn". Howe (1969, p. 1335) found that diagnostic Richmond Group brachiopods occur in the Arnheim and basal Fernvale Formations, whereas Maquoketa Group brachiopods are restricted to higher strata.

Grewingkia canadensis (Billings, 1862) is the only solitary coral known from the Richmond Group in the Nashville Dome area. The corals were abraded (Pl. 10, fig. 1) and deposited on their sides before burial. Epizoic bryozoans are rare, and were seen on only

two of 36 specimens. Borings assigned to *Trypanites weisei* are rare. Microscopic algal borings were seen in only one of nine corals for which thin sections were examined, but the stereozone is poorly preserved in specimens from this area.

The length-frequency distribution for corals in the Arnheim Formation suggests that most if not all were transported from elsewhere, as previously discussed for *G. canadensis* under "Cincinnati Arch Region" (Text-fig. 7). The source remains unknown because paleocurrent data are not available for this area. The number of major septa at a particular diameter in corals from the Arnheim Formation corresponds to those from "Waynesville" strata in the Cincinnati Arch region (Text-figs. 10, 17), suggesting that the solitary Rugosa lived in similar environments. Values for corals from the Fernvale Formation are similar to those from the "Liberty" of the Cincinnati Arch region.

Solitary Rugosa in a thin, fossiliferous lens within the Sequatchie Formation (interval 16b-2 of section 16) are unusually long and broad (UCGM 45517,

45518, 45521). They exceed 60 mm in length, which is thought to be the maximum size removed by currents from an initial population (Text-fig. 7). These corals may have lived in the Goodlettsville area, or been transported in higher energy conditions than occurred elsewhere. Values for the number of major septa at a particular diameter are typical of the "Whitewater-Elkhorn" in the Cincinnati Arch region (Text-figs. 10, 17). Corals in another similar lens within the Sequatchie Formation (interval 16c-1 of section 16) have a length-frequency distribution suggesting that they were transported from elsewhere, as previously discussed (Text-fig. 7). Two of the 16 specimens collected from this interval had the stereozone completely removed prior to deposition, indicating extensive abrasion. Values for the number of major septa at a particular diameter are typical of the "Waynesville" in the Cincinnati Arch region and Arnheim Formation of Tennessee (Text-figs. 10, 17). It is possible that corals in this lens were reworked from the Arnheim and deposited in the clastic Sequatchie tongue. They are slender, having diameters similar to specimens in the Arnheim Formation and in the northwestern and eastern Cincinnati Arch region (Text-fig. 8). One specimen (UCGM 45533) consists of three small coralla, but it is not known if these represent a pseudocolony or colony.

Little Sturgeon Bay, Wisconsin

Allen and Stieglitz (1981) recognized the Scales Shale, Fort Atkinson Dolomite, and Brainard Shale units of the Maquoketa Group in eastern Wisconsin. Silicified, poorly preserved specimens of *Grewingkia canadensis* (Billings, 1862) and typical Richmond Group colonial corals occur in dolomite at the top of the group at Little Sturgeon Bay (Text-fig. 2, area No. 4; Text-fig. 18). Chamberlin (1883, p. 171) reported that carbonate beds in this area grade into shales toward the south and west. The dolomite beds containing these corals may represent a westward shift of the Richmond Group facies associated with regression of the epicontinental sea at the end of Richmondian time. Unstudied solitary corals also occur in the Fort Atkinson Dolomite in eastern Wisconsin (P. E. Allen, 1981, pers. comm.). If these prove to be species characteristic of the Richmond Group rather than of the Maquoketa Group in Illinois and Iowa, intertonguing of the two units would be indicated. The section at Little Sturgeon Bay may be crucial in correlating Upper Ordovician type sections of the Cincinnati Arch region with strata to the west.

Little Bay de Noc, Michigan

In northern Michigan, the Richmond Group is exposed on the peninsula between Little Bay de Noc and Big Bay de Noc (Text-fig. 2, area No. 5; Text-fig. 18). It comprises the upper Stonington, Big Hill, and Mormon Creek Formations. Conodonts in the Stonington and Big Hill indicate a late Maysvillian-Richmondian age (Votaw, 1981). The basal beds of the 12 m thick Bay de Noc Member of the Stonington Formation are considered Maysvillian (Liberty and Sheldon, 1968, fig. 8, p. 28). The Richmondian portion consists of rubbly-bedded argillaceous limestone with gray shale interbeds (Hussey, 1926, p. 149; 1950, pp. 16, 17). The proportion of limestone and abundance of fossils increase upward. At locality 17a, a few pelecypods and trilobites occur in the lower part, and brachiopods and some bryozoans are present in thin lenses and beds within limestone higher in the member. Hussey (1950, pp. 17, 18) listed the fauna. Foerste (1918, p. 99) found a solitary coral, assigned herein to *Streptelasma divaricans* (Nicholson, 1875b), 3 m below the top. The specimen consists of two adjacent coralla near the anterior margin of a pedicle valve of *Rafinesquina* (Pl. 3, fig. 14s). Foerste also found solitary corals, assigned herein to *Grewingkia deltensis* n. sp., at the top of the member. The Bay de Noc Member probably represents a shallowing upward sequence deposited in a normal marine environment. Foerste (1918, pp. 125, 126) suggested that fossils in this member (his "argillaceous Richmond limestone") "may represent a late stage of the Waynesville fauna or an early stage of the post-Waynesville." Hussey (1926, p. 144) noted that the presence of many "Waynesville" and "Whitewater" fossils together with "Elkhorn" taxa made positive correlation unwise, but suggested that the upper part of the Bay de Noc Member may be "Whitewater" in age. The position of the Bay de Noc Member at the base of the Richmondian stratigraphic section, the general lithology and abundance of shale, and the rarity of solitary corals suggest it may correlate with the "Arnheim-Waynesville" interval in the Cincinnati Arch region.

The overlying Ogontz Member of the Stonington Formation is 1 to 6 m thick and consists of cherty, relatively pure micritic limestone with argillaceous material in irregular bands and lenses. An intraformational conglomerate of irregular nodules and thin slabs of Ogontz limestone is present near the top of the member (Hussey, 1926, pp. 135-138; 1950, p. 17). Hussey (1950, pp. 19, 20) listed the fauna. *Grewingkia deltensis* is common on some surfaces of Ogontz limestone, where individuals tend to occur in groups, in

association with small gastropods and some brachiopods. These corals were abraded and their tips rounded before burial (Pl. 11, figs. 1, 9). Of the specimens observed *in situ*, two were buried with the counter side "up", six had an alar side "up", and one had the cardinal side "up". *G. deltensis* is trochoid, moderately curved, and attains large size. It resembles species of *Grewingkia* in the Red River Formation (upper Middle or Upper Ordovician) of southern Manitoba, which were probably oriented during life with the convex cardinal side in the sediment and counter side facing upward (Elias, 1980, fig. 5; 1981). None of the collected specimens have epizoans or borings assigned to *Trypanites weisei*. Both corals for which thin sections were examined have Ordovician microscopic algal borings, and one also has similar modern borings produced by algae in Lake Michigan (Pl. 11, fig. 8). The Ogontz Member was deposited in a shallow marine environment with little terrigenous influx, possibly in a sheltered lagoon as suggested by the micritic composition and common gastropods. The intraformational conglomerate may indicate a period of subaerial exposure near the end of Ogontz deposition. The relatively pure micritic limestone characterizing this member is not found elsewhere in the Richmond Group. Foerste (1918, p. 125) provisionally correlated this unit (his "cherty Richmond limestone") with the "post-Waynesville" on the basis of the fauna. Hussey (1926, p. 144) suggested that it may be equivalent to the "Whitewater". The position of the Ogontz Member in the stratigraphic sequence, the predominance of limestone, and the relative abundance of solitary corals suggest it may correlate with the "Liberty".

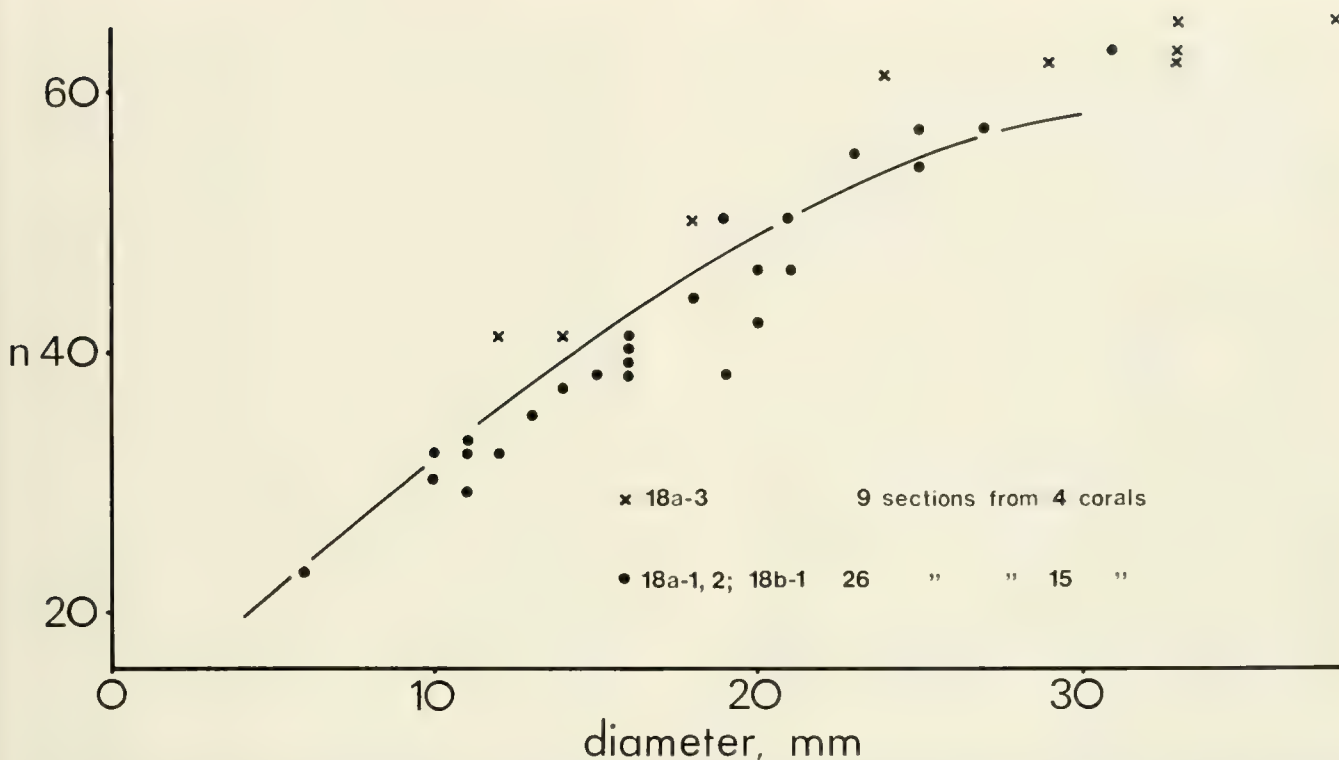
Overlying the Stonington Formation is the 38 m thick Big Hill Formation. It consists of dolomite with some shale partings (Ehlers, Kesling, and Slaughter, 1967, p. 225). In a quarry near the base of the formation (locality 17b), burrows and planar laminae are present. Hussey (1950, pp. 21, 22) listed the fauna. Abundant colonial corals of *Palaeophyllum* and *Halysites* (= *Catenipora*) and numerous bryozoans occur throughout the unit (Ehlers, Kesling, and Slaughter, 1967, p. 228). Near the base, the typical Richmond Group colonial corals *Calapoecia*, *Palaeophyllum*, *Favistella* (?= *Favistina*), and *Halysites* (= *Catenipora*) are abundant (Hussey, 1926, p. 145; 1950, p. 21). Near the top, *Palaeophyllum* and *Halysites* (= *Catenipora*) were reported (Ehlers, Kesling, and Slaughter, 1967, p. 225). Solitary corals are rare to common in association with colonial forms near the base of the formation at locality 17c, but are too poorly preserved for identification. Ehlers, Kesling, and Slaughter (1967, p. 225) reported solitary *Rugosa* below the very

fossiliferous colonial coral beds at the top of the unit. The lithology and sedimentary structures of the Big Hill Formation suggest deposition in periodically semi-restricted, shallow marine environments, perhaps frequently in lagoons behind colonial coral banks. The formation resembles the Saluda Dolomite Member of the western Cincinnati Arch region. Hussey (1926, pp. 148–150) considered correlation of the Big Hill Formation uncertain, but suggested it may be near the "Whitewater-Elkhorn". Its stratigraphic position above the Ogontz Member but below the Mormon Creek Formation, the dolomitic composition, and the presence of colonial coral beds and solitary corals suggest correlation with the "Whitewater".

The 36 m thick Mormon Creek Formation overlies the Big Hill Formation (Kesling, 1975, pp. 5–7). It consists of thinly-bedded dolomite alternating with bands of shale, and contains gypsum and hopper-shaped halite molds. One species of ostracode is abundant on some bedding planes, and trace fossils are present at certain horizons. Kesling (1975, p. 6) considered the formation to have been deposited in a brine-filled, restricted basin. Evaporite-producing environments did not occur elsewhere in eastern North America during the latest Ordovician. The position of the Mormon Creek Formation as the final unit in a regressive sequence at the top of the Richmondian stratigraphic section suggests that it may correlate with the "Elkhorn".

Drummond Island, Michigan

The Richmond Group is exposed on the north shore of Drummond Island (Text-fig. 2, area No. 6; Text-fig. 18). South of locality 18a, Hussey (1952, pp. 49, 50) reported a stromatoporoid "reef" extending under the water, overlain by 2 m of sandy dolomitic limestone, followed by another stromatoporoid-colonial coral "reef". These "reefs" are equivalent to similar biostromes at the top of the Meaford beds on Manitoulin Island, Ontario. Hussey termed these strata "Whitewater member", and listed the fauna. At locality 18a, 0.5 m of rubbly limestone with uncommon to common solitary corals and a few brachiopods (interval 18a-1) is overlain by a 0.3 m thick colonial coral bed with the typical Richmond Group genera *Favistina* and *Calapoecia* and uncommon solitary corals (interval 18a-2). Many of the colonial corals are overturned. This bed is overlain by 0.6 m of more massive limestone containing abundant solitary *Rugosa* and sparse brachiopods at the top (interval 18a-3). Orientation of the solitary corals is shown in Text-figure 5. At locality 18b, the rubbly-bedded, argillaceous limestones and shales of the Meaford beds are exposed (Hussey, 1952, pp.



Text-figure 19.—Relation between number of major septa (n) and coral diameter in *Grewingkia canadensis* (Billings, 1862) from intervals within the upper Meaford beds, upper member, Georgian Bay Formation, Drummond Island, Michigan (see Text-fig. 18 for stratigraphic positions). Curve represents averages for the entire Richmond Group, Cincinnati Arch region (see Text-fig. 33).

50, 51). Near the base of the section, several fossiliferous surfaces with brachiopods, branching bryozoans, and uncommon to common solitary corals are present. The fauna was listed by Hussey (1952, p. 51). North of locality 18c, Hussey (1952, p. 50) reported Meaford beds (his "Whitewater member") and listed the fauna. At locality 18c, massive, thickly-bedded, vuggy dolomite with branching bryozoans represents the overlying Kagawong beds of Manitoulin Island. Solitary corals were not seen in this unit on Drummond Island.

Grewingkia canadensis (Billings, 1862) is the only solitary rugose coral known from Drummond Island. The corals were abraded before final burial (Pl. 10, fig. 15). In intervals 18a-1 to 3 and 18b-1 of section 18, sixteen of 19 specimens were oriented at the time of final burial with an alar side "up", two with the count-

er side "up", and one with the cardinal side "up". The length-frequency distribution is bimodal, suggesting that some corals were removed from the area, as previously discussed for *G. canadensis* under "Cincinnati Arch Region" (Text-fig. 7). Very long specimens are relatively common in the solitary coral bed of interval 18a-3. Coral diameters are similar to those of specimens from the northwestern and eastern Cincinnati Arch region and Manitoulin Island (Text-fig. 8). The distribution of the number of major septa at a particular diameter for specimens from intervals 18a-1 and 2, and 18b-1 in the upper Meaford beds of Drummond Island is similar to that for the "Waynesville" in the Cincinnati Arch region (Text-figs. 10, 19). The higher values in the horn coral bed (interval 18a-3) immediately above intervals 18a-1 and 2 resemble those for the "Whitewater-Elkhorn", possibly indi-

Table 2.—Frequency (f) of values on the axial region comparative scale (see Pl. 7, figs. 1–21) for specimens of *Grewingkia canadensis* (Billings, 1862) from the Meaford beds, upper member, Georgian Bay Formation, Drummond Island, Michigan, and Manitoulin Island, Ontario. n = number of specimens.

Axial Region Comparative Scale Values:		0	10	20	30	40	50	60	70	80	90	100
Drummond Is., $n=7$	f :	—	—	1	3	2	—	—	—	1	—	
Manitoulin Is., $n=9$	f :	—	—	1	2	—	1	3	2	—	—	

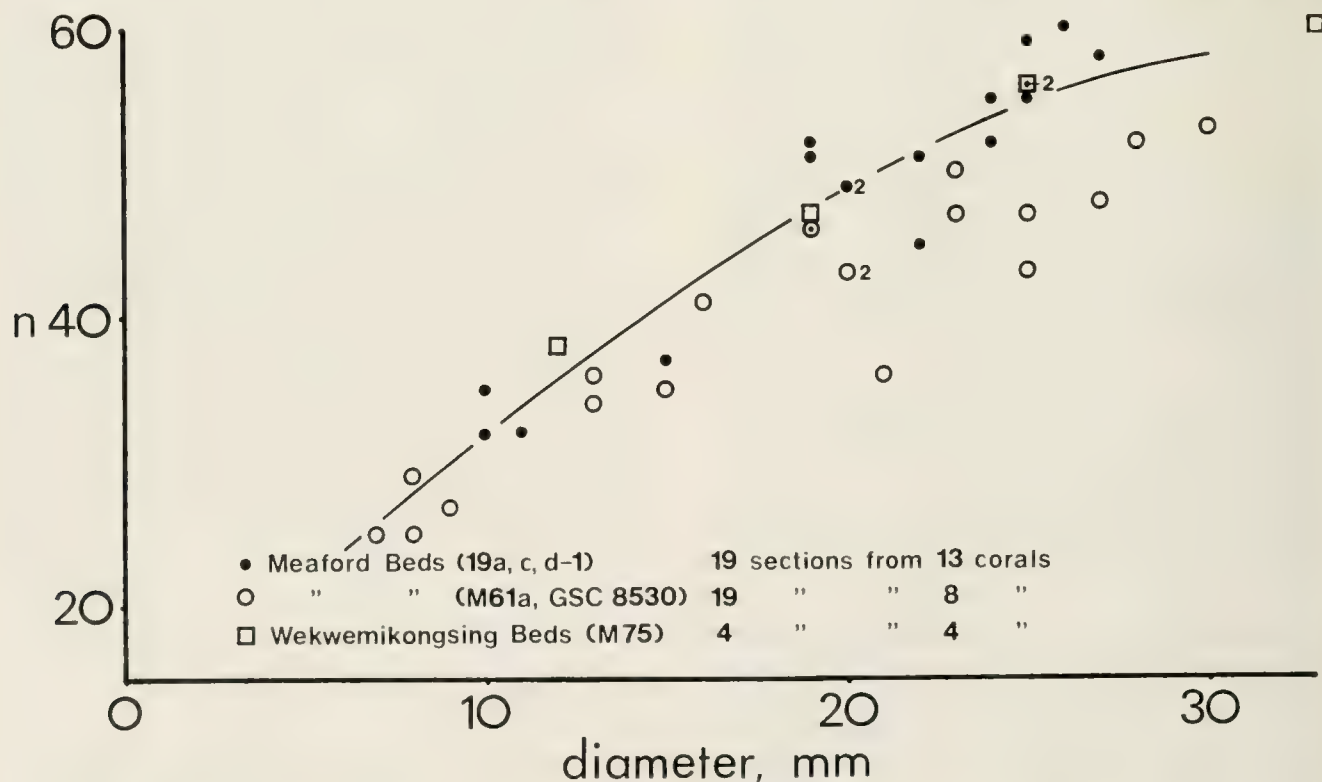
cating shallower water. The frequency distribution of values on the axial region comparative scale for the few available specimens has a peak at 35, as does the distribution for the "Waynesville-Liberty" in the Cincinnati Arch region (Table 2; Text-fig. 12). Epizoic bryozoans and borings assigned to *Trypanites weisei* appear to be rare at Drummond Island. Microscopic algal borings are present in all five corals for which thin sections were examined.

Manitoulin Island, Ontario

The Richmondian stratigraphy and fauna of Manitoulin Island (Text-fig. 2, area No. 7; Text-fig. 18) were described by Foerste (1912b; 1916, pp. 97-127; 1924, pp. 53, 54) and Caley (1936). The strata are presently included in the Georgian Bay Formation, which is Maysvillian and Richmondian in age (Liberty and Shelden, 1968, pp. 30, 31, fig. 8; Liberty, 1969, pp. 73-79). The upper, Richmondian portion of its 45 to 100 m thick lower member (Wekwemikongsing beds) consists of shale, with a few thin dolomite interbeds toward the top. Brachiopods, bryozoans, pelecypods, and gastropods are the dominant fossils. Solitary corals assigned to *Grewingkia canadensis* (Billings, 1862) occur in a dolomite bed near the top of the Wek-

wemikongsing beds at locality M75. The distribution of the number of septa at a particular coral diameter is similar to that for "Liberty" strata in the Cincinnati Arch region (Text-figs. 10, 20). The lower member of the Georgian Bay Formation appears to have been deposited in a normal marine environment, and the upward increase in the frequency of carbonate beds and fossils may indicate a shallowing sequence. The stratigraphic position of the upper portion of the lower member and the abundance of shale suggest it may correlate with the "Arnheim-Waynesville" of the Cincinnati Arch region.

The overlying Meaford beds of the upper member of the Georgian Bay Formation consist of about 15 m of rubbly-bedded, argillaceous limestone with gray shale interbeds. Brachiopods and branching bryozoans are the most common fossils. Typical Richmond Group colonial coral-stromatoporoid beds occur near the base and top of the unit. The fauna and lithology suggest deposition in a shallow, normal marine environment with colonial coral-stromatoporoid banks developing at the beginning and end of deposition. The upward increase in limestone at locality 19d may indicate a shallowing sequence. Foerste (1916, p. 104; 1924, p. 51) considered the fauna of the Meaford beds



Text-figure 20.—Relation between number of major septa (n) and coral diameter in *Grewingkia canadensis* (Billings, 1862) from intervals within the Georgian Bay Formation, Manitoulin Island, Ontario (see Text-fig. 18 for locations and stratigraphic positions). Numbers indicate frequency of a point if greater than one. Curve represents averages for the entire Richmond Group, Cincinnati Arch region (see Text-fig. 33).

to be upper "Waynesville". The stratigraphic position and predominance of limestone suggest correlation with the "Liberty".

Grewingkia canadensis is rare to common at seven of ten Meaford exposures that were examined. Specimens are most frequent near the base and top of the unit, and usually occur with brachiopods and branching bryozoans. At locality 19a they are associated with gastropods and brachiopods. Solitary corals are absent in most of the colonial coral-stromatoporoid beds that were seen, but are rare in the *Favistina* bed at the top of the Meaford in interval 19d-3 at locality 19d. Epizoic bryozoans and borings assigned to *Trypanites weisei* are uncommon. Microscopic algal borings are present in six of eight corals for which thin sections were examined. Solitary corals from localities 19a to e were abraded before final burial (Pl. 10, fig. 24). The length-frequency distribution of specimens from these localities suggests that they were transported from elsewhere, as previously discussed for *G. canadensis* under "Cincinnati Arch Region" (Text-fig. 7). Their diameters are similar to specimens from Drummond Island and the northwestern and eastern Cincinnati Arch region (Text-fig. 8). The distribution of the number of major septa at a particular diameter for localities 19a, c, and d corresponds to that for corals from "Liberty" strata in the Cincinnati Arch region (Text-figs. 10, 20). The frequency distribution of values on the axial region comparative scale for the few available specimens has peaks at 35 and 65, as does the distribution for the "Whitewater-Elkhorn" in the Cincinnati Arch region (Table 2; Text-fig. 12).

Large specimens of *G. canadensis* that generally show little evidence of abrasion have been collected in Meaford beds to the east of localities 19a to e at Manitowaning (locality M61a; GSC 8530, 8530a, e-j), Clay Cliffs (GSC 8528, 8528a-d; GSC 8529b, c; GSC 8573a-c), and Cape Smith (GSC 1982, 1982a-g, i-l) on Manitoulin Island (Pl. 10, figs. 18, 19; see Text-fig. 18 for locations). They are thought to represent a population that did not undergo extensive transport. The distribution of the number of major septa at a particular diameter is similar to that for specimens from "Waynesville" strata in the Cincinnati Arch region (Text-figs. 10, 20), suggesting that these corals may have lived in slightly deeper water than those found elsewhere in the Meaford beds or in the uppermost Wekwemikong beds.

Except for a single, small, abraded specimen of *Grewingkia rustica* (Billings, 1858a) found in basal Meaford beds at locality 19b (Pl. 11, fig. 24), this species is known only from Lake St. John, Québec. The Manitoulin Island specimen may have been trans-

ported from the east. Corals of *Streptelasma divaricans* (Nicholson, 1875b) that are attached to bryozoans are rare near the base of the Meaford beds at locality M61a (Pl. 3, figs. 16, 17s, 18s). The absence of this species in Meaford beds to the west may indicate that favorable substrates were seldom stabilized during periods of non-deposition.

Copper and Grawbarger (1978) studied the paleoecologic succession leading to a lower Meaford biostrome on eastern Manitoulin Island. Solitary corals were not observed in the "level bottom" community occupying a muddy substrate, but were reported in the "wave baffle margin", "protected subtidal", and biostromal "wave baffle" communities where carbonate sediments were deposited.

Overlying the Meaford beds, the Kagawong beds of the upper member of the Georgian Bay Formation consist of about 30 m of generally massive dolomite, dolomitic limestone, and limestone. Burrowed strata and branching bryozoan beds are present. Cross-bedding, fine planar laminae, and gastropod-pelecypod beds are less common. Stromatoporoid-colonial coral biostromes occur near the base and top of the unit. *Streptelasma divaricans* is rare, and was found at only two of 15 Kagawong exposures that were examined. At locality 19f, in the middle of the unit, the species is rare to uncommon in association with branching bryozoans and brachiopods. One coral was attached to a pelecypod. The lithology, fauna, and structures such as burrows and fine planar laminae suggest that the Kagawong beds were deposited in a periodically semi-restricted, shallow marine environment, perhaps occasionally behind colonial coral-stromatoporoid banks. Cross-bedded strata indicate periods of higher energy conditions. The association of brachiopods, bryozoans, and rare solitary corals in the middle of the unit suggests that more normal marine conditions existed during mid-Kagawong deposition. Foerste (1916, p. 104; 1924, p. 52) and Caley (1936, p. 43) considered the Kagawong beds to be equivalent to the Saluda or "Whitewater" of the Cincinnati Arch region on the basis of fauna and lithology. The stratigraphic position at the top of the Richmond Group suggests correlation with the "Whitewater-Elkhorn".

Meaford, Ontario

Fritz (1926) described the Ordovician stratigraphy and paleontology in the vicinity of Meaford (Text-fig. 2, area No. 8; Text-fig. 18). Richmondian strata are presently included in the Georgian Bay Formation and overlying Queenston Formation (Liberty, 1969, pp. 73-83). Foerste (1916, pp. 129, 130) listed solitary corals, together with stromatoporoids and the colonial

corals *Tetradium*, *Columnaria* (?=*Favistina*), and *Calapoecia* from the richly fossiliferous limestone and shale (Vincent Member of Fritz, 1926, pp. 93, 94; upper Georgian Bay Formation of Liberty, 1969, pp. 73–79) immediately beneath the Queenston Formation red shales. A transverse section of one of his specimens (GSC 8531) shows it to be *Grewingkia canadensis* (Billings, 1862). Epizoic and boring bryozoans have been observed on solitary Rugosa in Foerste's collection (GSC 8531a and 8531b, respectively). Another specimen (ROM 12325) is associated with bryozoans and brachiopods in calcarenite. Foerste (1916) considered these strata to be "Waynesville" in age, but their position in the stratigraphic sequence and the presence of solitary and colonial corals suggest they may be equivalent to the "Liberty-Whitewater" in the Cincinnati Arch region. Czurda, Winder, and Quigley (1973, p. 1803) concluded that detrital quartz and heavy minerals within the Georgian Bay Formation were derived from the Canadian Shield to the north, suggesting that it was positive. The Queenston delta prograded over the Richmond Group lithology (Georgian Bay Formation) in this area. The Queenston Formation may correlate with the "Whitewater-Elkhorn", as suggested by its stratigraphic position. Liberty (1969, p. 81) noted a strong paleontological correlation of the Queenston with the highest "Whitewater" and Saluda.

On Bruce Peninsula northwest of Meaford, several colonial coral biostromes occur within the Queenston Formation (Liberty and Bolton, 1971, pp. 25–28). These are thought to correlate with the Kagawong beds of Manitoulin Island. Liberty and Bolton (1971, p. 126) listed solitary corals from several localities.

Streetsville, Ontario

Dyer (1925a, 1925b) described the Ordovician stratigraphy and paleontology in the vicinity of Streetsville, near Toronto (Text-fig. 2, area No. 9; Text-fig. 18). Richmondian strata are presently included in the Georgian Bay Formation and overlying Queenston Formation (Liberty, 1969, pp. 73–83). Foerste (1916, p. 133) reported rare, very small solitary corals in a local incursion of Richmond Group limestone and shale (*Columnaria* reef, Meadowvale Member of Dyer, 1925b, p. 125; upper Georgian Bay Formation of Liberty, 1969, pp. 73–79) "a short distance" (Foerste, 1916, p. 133) beneath the Queenston Formation red shales. A small, poorly preserved specimen with dilated septa (ROM 335HR) is herein referred to as *Grewingkia*? sp. If these small corals are *G. canadensis*, they may represent the smallest size fraction that was transported farthest toward shore from an

initial population (see discussion for *G. canadensis* under "Cincinnati Arch Region"). Foerste also reported specimens of the colonial coral *Calapoecia*, as well as bryozoans and gastropods. He stated that the fauna suggested "Whitewater" affinities to E. O. Ulrich. Dyer (1925b, p. 125) suggested correlation with the Saluda or "Whitewater" in the Cincinnati Arch region. On the basis of stratigraphic position, these strata may be equivalent to the "Liberty", with the "Whitewater-Elkhorn" represented by the Queenston Formation. Czurda, Winder, and Quigley (1973, p. 1803) suggested that detrital quartz and heavy minerals within the Georgian Bay Formation in this area were derived from the Taconic Mountains to the east.

Montréal, Québec

Richmondian stratigraphy in the vicinity of Montréal (Text-fig. 2, area No. 10; Text-fig. 18) has been summarized by Clark and Stearn (1963, p. 40). The 48 m thick Pontgravé River Formation comprises calcareous marine shale and limestone. The overlying Bécancour River Formation is more than 600 m thick, and consists of the basal 15 m thick Carmel River Member, a non-marine gray shale, overlain by red and green non-marine shale and sandstone of the Queenston facies.

Foerste (1916, pp. 153, 155) reported solitary corals from fossiliferous "Waynesville" beds (Pontgravé River Formation) beneath the Queenston red shales (Bécancour River Formation) at St. Hilaire and St. Hugues. At St. Hilaire, brachiopods, pelecypods, and gastropods were also listed. The corals are associated with brachiopods at St. Hugues, where they occur in glacial erratics that probably came from a nearby source. Foerste (1916, p. 145) found one solitary coral as well as brachiopods in a sequence termed "Waynesville" (Pontgravé River Formation) at the Nicolet River section. Richmondian solitary corals from the vicinity of Montréal were assigned to *Strepelasma rusticum* by Foerste, but their identity is uncertain because specimens have not been located for sectioning.

Lake St. John, Québec

At Snake Island, Lake St. John (Text-fig. 2, area No. 11; Text-fig. 18) solitary rugose corals are "thrown up in great numbers by the waves from some [limestone] stratum below water-level" (Foerste, 1924, p. 65). Foerste (1916, pp. 156–158) listed the fauna, including solitary corals, the typical Richmond Group colonial genera *Columnaria* (?=*Favistina*), *Calapoecia*, *Lyopora*, and *Tetradium*, and stromatoporoids, from *in situ* strata at water level.

Grewingkia rustica (Billings, 1858a) is the only solitary coral known from Lake St. John. The species is externally very similar to *G. canadensis*, being ceratoid to trochoid and straight to slightly curved in early and intermediate stages, and cylindrical in later stages (Pl. 11, figs. 16, 20). The specimens are water-worn, but this abrasion may be at least partly of recent origin. Epizoic bryozoans occur on five of 18 corals. Four of the bryozoans are on the counter side of their host, three on an alar side, and four on the cardinal side. Borings assigned to *Trypanites weisei* are present in seven of 18 specimens, and most are located on the cardinal side. The microscopic algal borings present in all five corals for which thin sections were examined may be Ordovician and (or) Holocene in age (Pl. 11, fig. 29). They are generally very fine, and appear to differ from those of the Cincinnati Arch region.

Foerste (1916, p. 156) provisionally correlated these strata at Lake St. John with the "Whitewater".

MAQUOKETA GROUP

Introduction

The Maquoketa Group (Text-fig. 2) is Edenian through Richmondian in age (Templeton and Willman, 1963, pp. 130, 131). The source area of this marine clastic wedge was to the east, and the unit rapidly thins from nearly 300 m in eastern Indiana (including the Richmond Group at the top) to about 60 m in western Indiana (Gray, 1972, pp. 1, 4), Illinois (Willman and Buschbach, 1975, p. 82), and Iowa (Ladd, 1929, p. 331) (see Gutstadt, 1958, figs. 7–9). In Indiana, Gray (1972, fig. 4) recognized deep basin sediments in the southwest and shelf deposits to the north and east. The Maquoketa Group is predominantly gray shale. The Neda Formation occurs locally at the top of the group in Iowa (Agnew, 1955, p. 1717), Wisconsin, northern Illinois (Willman and Buschbach, 1975, p. 86), and possibly northeastern Indiana (Gray, 1972, p. 19). It is generally less than 3 m thick, and consists of red shale interbedded with oölitic hematite. A few Maquoketa species were reported from the formation by Savage and Ross (1916). The Neda is thought to be a western tongue of the Queenston delta (Willman and Buschbach, 1975, p. 86). Only the Edenian through Maysvillian Scales Formation is present in southeastern Minnesota. Bayer (1965, p. 45) indicated that clastic material in the Elgin Member of this formation probably marks the western edge of detritus shed from the Taconic Mountains, while sand in the overlying Clermont Member carbonates was derived from an uplift of the Transcontinental Arch to the west (Bayer, 1965, p. 44; Austin, 1972, p. 470). The remainder of the Cincinnati sequence in Minnesota was eroded

prior to deposition of the overlying Devonian unit (Austin, 1972, p. 470). Upper Ordovician strata become thinner and the terrigenous sand and carbonate content in the Maquoketa Group increases toward the Ozark Dome, which was probably slightly positive, as seen in the vicinity of Thebes, southern Illinois (Templeton and Willman, 1963, p. 131; Bayer, 1965, p. 45). The Maquoketa is termed Sylvan Shale in Oklahoma (Ladd, 1929, pp. 311, 407; Templeton and Willman, 1963, p. 192).

Northeastern Iowa

The stratigraphy and fauna of the Maquoketa Group in northeastern Iowa (Text-fig. 2, area No. 12; Text-fig. 18) have been described by Savage (1905), Calvin (1906), and Ladd (1929). The lowermost Richmondian unit is the Clermont Member of the Scales Formation. This gray shale contains a fauna dominated by brachiopods. Ladd (1929, p. 391) listed a solitary coral from the Clermont Member, and described and figured a specimen possibly from the Clermont that he assigned to *Streptelasma haysii* (Meek, 1865) (Ladd, 1929, p. 397, pl. 4, figs. 1, 2). This specimen (SUI 2-050) has not been located, and so its identity remains uncertain. Another coral probably from the same unit is herein assigned to *Helicelasma randi* Elias (1981). The overlying Fort Atkinson Formation consists of dolomite and limestone containing brachiopods and echinoderm fragments. *Bighornia* cf. *B. patella* (A. E. Wilson, 1926) occurs in this unit. One of the three known specimens has borings assigned to *Trypanites weisei* (Pl. 14, fig. 23). The Brainard Formation overlies the Fort Atkinson, and consists of gray shale with some limestone beds at the bottom and top. It contains bryozoans and brachiopods. One specimen of *Helicelasma randi* is known from the top of the formation in Clayton County, at the southern extremity of this area. The septal grooves and interseptal ridges are preserved, indicating little abrasion prior to burial. Savage (1905, p. 487) listed solitary corals throughout the Maquoketa Group in Fayette County.

Templeton and Willman (1963, pp. 132, 133) considered the Clermont Member similar in lithology and stratigraphic position to the "Arnheim" of the Richmond Group in the Cincinnati Arch region. They noted that the Fort Atkinson Formation and "Waynesville" are remarkably similar in fauna, lithology, and stratigraphic position. The Brainard Formation was correlated with the "Liberty-Whitewater-Elkhorn" primarily on the basis of lithology. Faunal correlation of the Brainard Formation and its uppermost *Cornulites* zone with the "Elkhorn" was considered highly probable by Ladd (1929, pp. 369, 370).

Southeastern Iowa and Northwestern Illinois

In southeastern Iowa and northwestern Illinois (Text-fig. 2, area No. 13; Text-fig. 18), the Maquoketa Group is predominantly gray shale, much of it unfossiliferous (Ladd, 1929, p. 330; Savage, 1925, pp. 240–245; Willman and Buschbach, 1975, p. 86). Near the top, fossiliferous limestone interbeds with brachiopods and bryozoans are present. Ladd (1929, pp. 371, 391–395) termed this the *Cornulites* zone and listed the fauna. Votaw and Kolata (1981) recognized the Scales Shale, Fort Atkinson Limestone, and Brainard Shale within the Maquoketa Group in northern Illinois. They assigned the latter two units to conodont Fauna 12 (Sweet, Ethington, and Barnes, 1971), indicating a late Maysvillian–Richmondian age for the upper Maquoketa. The solitary coral *Helicelasma randi* Elias (1981) occurs in argillaceous limestone beds in the upper Brainard at Sterling, Illinois, where stratigraphic sections were described and the fauna was listed by Savage (1925, pp. 240–245). The septal grooves and interseptal ridges are generally preserved, indicating little abrasion prior to burial (Pl. 6, figs. 1, 2, 5). Of the epizoic bryozoans observed on eight corals, six are on the counter side, seven on an alar side, and three are on the cardinal side (Pl. 6, fig. 2). Ladd (1929, p. 391) listed a solitary coral from the *Cornulites* zone in southeastern Iowa, and Savage (1925, p. 244) listed them as rare in fossiliferous limestone beds of the upper Maquoketa Group near Preston, Iowa.

Thebes, Illinois

In the vicinity of Thebes (Text-fig. 2, area No. 14; Text-fig. 18), the Maquoketa Group comprises the Thebes and Orchard Creek Members of the Scales Formation. The Maquoketa is overlain by the Girardeau Formation (Willman and Buschbach, 1975, pp. 86, 87, fig. O-27). The Thebes Member has a maximum thickness of 48 m, and consists of silty, fine-grained sandstone in medium to thick beds and local cross-beds. Trace fossils occur in the upper part of the member. It grades or intertongues eastward and northward into shales of the lower Elgin Member. The overlying Orchard Creek Member is 3 to 9 m thick and is predominantly gray shale. It may be equivalent to the Elgin Member, but could be as young as the Brainard Formation (Willman and Buschbach, 1975, p. 86). Kolata and Guensburg (1979, p. 1122) suggested a Richmondian age on the basis of crinoids. The Orchard Creek fauna, including brachiopods, molluscs, and trilobites, occurs in calcareous layers, and was listed and described by Savage (1917b, pp. 263, 264). Pryor and Ross (1962, p. 9) listed a graptolite, and Kolata and Guensburg (1979) described a “carpoid”. Solitary corals

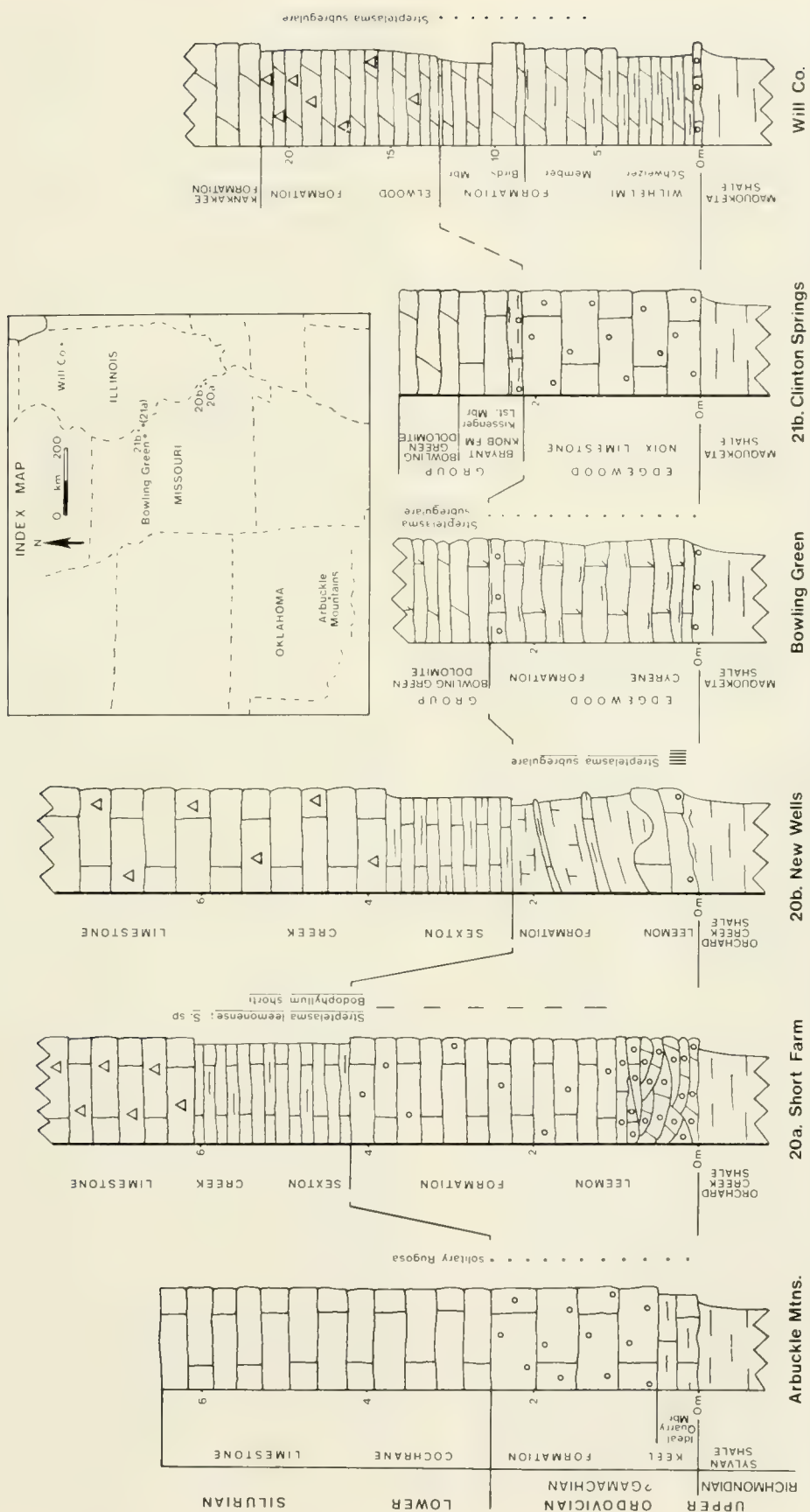
are rare. Only two specimens of *Helicelasma randi* Elias (1981) have been collected from the Orchard Creek (Mississippi River section of Pryor and Ross, 1962, fig. 3; section B of Satterfield, 1971, fig. 1; locality 1 of Kolata and Guensburg, 1979, fig. 1). The member grades upward into the Girardeau Formation, which is up to about 9 m thick (Satterfield, 1971, p. 266). It consists of unevenly-bedded, fine-grained to lithographic limestone with shale partings and siliceous interbeds and nodules. The Girardeau may be equivalent to the Fort Atkinson Formation, but an age as young as or younger than the Brainard is presently favored (Willman and Buschbach, 1975, p. 87). The fauna, including echinoderms, bryozoans, brachiopods, molluscs, and trilobites, was described by Savage (1917a). Conodonts of the Girardeau indicate a very late Ordovician age (Satterfield, 1971). Brower (1973, p. 265) suggested a Richmondian or younger (Gamachian) age for the crinoids.

UPPERMOST ORDOVICIAN OF OKLAHOMA, MISSOURI AND ILLINOIS

Introduction

Thompson and Satterfield (1975) revised the stratigraphy and studied conodonts contiguous to the Ordovician-Silurian boundary in eastern Missouri (Text-fig. 2, area No. 16, 17). Their work indicated that strata previously included at the base of the Lower Silurian Edgewood Group of the Alexandrian Series (Savage, 1908, 1917a) are Late Ordovician in age. These strata comprise the Noix Limestone and Cyrene Formation in Pike County, northeastern Missouri, and the Leemon Formation in Cape Girardeau County to the southeast (Text-fig. 21). The Noix Limestone lies disconformably above the Maquoketa Group and is disconformably overlain by a Lower Silurian sequence (Thompson and Satterfield, 1975, pp. 89, 103). While the Noix was being deposited, Cyrene strata formed immediately to the west. Deposition of the Leemon Formation on an eroded Maquoketa Group–Girardeau Formation surface was followed by a period of erosion preceding Early Silurian sedimentation (Thompson and Satterfield, 1975, p. 101). A late Ashgill age for the Noix Limestone and Leemon Formation was supported by Amsden's (1974) study of the brachiopods. Further conodont work has suggested that the Noix is Richmondian or younger Ordovician (McCracken, Barnes, and Kennedy, 1980; McCracken and Barnes, 1981, p. 72).

The Keel Formation at the base of the Chimneyhill Subgroup in the Arbuckle Mountains of Oklahoma (Text-fig. 2, area No. 15; Text-fig. 21) had been correlated with the Edgewood Group of Missouri, and



Text-figure 21.—Uppermost Ordovician stratigraphic sections (all except Will County to the same scale) and distribution of solitary rugose corals in Oklahoma, Missouri, and Illinois (see "Appendix: Collecting Localities", for further information). For explanations of symbols see legends in Text-figure 3.

was therefore placed in the Lower Silurian Alexandrian Series (Maxwell, 1936). It unconformably overlies the Sylvan Shale and is overlain, usually unconformably, by Silurian strata (Maxwell, 1936, p. 48; Amsden, 1974, p. 25). Amsden (1974, p. 26) found that all Keel Formation brachiopods occur in the Noix Limestone and many are present in the Leemon Formation. He therefore tentatively correlated these three units, thereby assigning the Keel Formation to the upper Ashgill Series.

Savage (1910) recognized the Alexandrian Series in northeast Illinois (Text-fig. 2, area No. 18), and named these strata the Channahon Limestone. He considered the fauna most closely related to the Edgewood of Missouri. Willman (1973, pp. 12–14) proposed the Wilhelmi Formation, which includes the Channahon Limestone, for sediments deposited in channels eroded in the underlying Neda Formation and Brainard Formation of the Maquoketa Group (Text-fig. 21). These deposits are herein correlated with the Cyrene and Leemon Formations of Missouri, as will be discussed under "Will County, Illinois".

Amsden (1974, p. 26) noted that the Keel-Edgewood brachiopods have little in common with North American forms, and the assemblage most closely resembles the *Hirnantia* fauna that occurs in the uppermost Ordovician Hirnantian Stage of the European Ashgill Series (Ingham and Wright, 1970; Text-fig. 1). This characteristic brachiopod-dominated fauna has been widely recognized in Great Britain, Scandinavia, northwestern Europe, northern Africa, Kazakhstan, and Burma (Wright, 1968; Lespérance, 1974). In North America, it may be present in siltstones near Ashland in Aroostook County, Maine (R. B. Neuman, 1968, p. 44; Ingham and Wright, 1970, p. 240; Lespérance, 1974, p. 14). Typical north European representatives occur in mudstone in the Percé area of Québec (Lespérance, 1974; Lespérance and Sheehan, 1976), and in quartz-bearing limestone on Anticosti Island, Québec (Cocks and Copper, 1981). Amsden (1974, p. 28) believed that the Keel-Edgewood brachiopod species were different from those of the *Hirnantia* fauna. He noted that the generic assemblages have similarities, but many genera of the *Hirnantia* fauna are not present in the Keel-Edgewood, and *vice versa*. However, as Amsden pointed out, the Keel-Edgewood fauna occurs in a carbonate facies, whereas the *Hirnantia* fauna is almost everywhere in mudstone. Amsden viewed the Hirnantian aspect of the Keel-Edgewood with caution because most genera common to the two units apparently have considerable ranges in the Late Ordovician–Early Silurian. Lespérance and Sheehan (1976, pp. 719, 720) stated that the Edgewood could

contain a latest Ordovician endemic assemblage derived from the *Hirnantia* fauna and other North European Province species, but considered more likely that it is Silurian with a few hold-overs from the Late Ordovician North American Province. With the stratigraphic revision and conodont biostratigraphy of Thompson and Satterfield (1975), the further conodont studies of McCracken, Barnes, and Kennedy (1980) and McCracken and Barnes (1981, p. 72), and the Ordovician aspect of the Keel-Edgewood brachiopod fauna, evidence points to a latest Ordovician age for the carbonate sequence of Oklahoma, Missouri, and Illinois.

If the upper Maquoketa Group is equivalent to the "Elkhorn" of the Richmond Group, as discussed previously under "Northeastern Iowa", it was deposited during latest Richmondian time. The uppermost Ordovician carbonate sequence in Oklahoma, Missouri, and Illinois unconformably overlies the Maquoketa, suggesting a post-Richmondian age. There is no evidence for comparable deposition above the Richmond Group in the Cincinnati Arch region, which is unconformably overlain by the middle Llandovery (Lower Silurian) Brassfield Formation. The Brassfield has been correlated with the Kankakee Formation of northeastern Illinois, the Sexton Creek Limestone of southwestern Illinois and southeastern Missouri (Willman and Atherton, 1975, p. 99), and the Cochrane Limestone of Oklahoma (Maxwell, 1936, fig. 4) (see Text-fig. 21). Latest Ordovician and earliest Silurian carbonate sedimentation above the Maquoketa Group probably occurred during the interval between deposition of the Richmond Group and Brassfield Formation. Schuchert and Twenhofel (1910, pp. 700, 701) established the Gamachian Stage to include the Ellis Bay Formation of Anticosti Island, Québec, and all American Ordovician strata later in age than the youngest Richmondian of Ohio and Indiana. Fauna 13 has been proposed for the lower Ellis Bay conodont assemblage, and is considered Gamachian (McCracken and Barnes, 1981, p. 64). Conodonts in the Noix Limestone indicate a Richmondian or younger Ordovician age, but they cannot be equated with those in the Ellis Bay (McCracken and Barnes, 1981, p. 72). The solitary coral *Streptelasma subregulare* (Savage, 1913) occurs in the Leemon, Cyrene, Wilhelmi, and possibly Keel Formations. It is similar to many specimens of *S. affine* (Billings, 1865), which is common in the Ellis Bay Formation, and most closely resembles *S. unicum* B. Neuman (1975), probably from the Hirnantian of Sweden. The Keel Formation of Oklahoma, the Leemon, Noix, and Cyrene Formations of Missouri, and the Wilhelmi Formation of Illinois are

herein tentatively considered to have been deposited during the Gamachian. Brachiopods suggest that these units may be equivalent to the Hirnantian Stage of Europe. On Anticosti Island, brachiopods indicate that the Hirnantian is equivalent to the upper part of the Gamachian (Cocks and Copper, 1981).

Uppermost Ordovician strata in Oklahoma, Missouri, and Illinois represent the initial transgression of a shallow epicontinental sea in which the Middle Paleozoic carbonate sequence of east-central North America was deposited (Amsden, 1974, p. 29). The timing of this transgression probably coincides with the latest Hirnantian transgression recognized in northwestern Europe (Brenchley and Newall, 1980, fig. 22), and suggests that deglaciation began in the latest Ordovician rather than during the Early Silurian as suggested by Berry and Boucot (1973). The predominance of oölitic and bioclastic limestones in Oklahoma, Missouri, and Illinois and the development of bioherms in Missouri indicate fairly high energy, shallow, normal marine conditions. The presence of terrigenous sand in southeastern Missouri suggests that the Ozark Dome may have been slightly positive at this time.

Arbuckle Mountains, Oklahoma

In the Arbuckle Mountains (Text-fig. 2, area No. 15; Text-fig. 21), the Keel Formation has a maximum thickness of about 4.5 m and comprises the lower Ideal Quarry Member (Hawkins Limestone of Maxwell, 1936, pp. 45–49) and an upper oölitic unit (Keel Limestone of Maxwell, 1936, pp. 50–54) (see Amsden, 1974, p. 25). The Ideal Quarry Member is only locally present and consists of thinly-bedded argillaceous limestone. Crinoid stems are common on bedding planes, but other fossils are rare. Maxwell (1936, table 1) listed solitary and colonial corals, a bryozoan, brachiopods, pelecypods, and a gastropod. This member grades upward into thickly-bedded oölitic limestone. Fossils are rare in the oölitic, from which Maxwell (1936, table 2) listed solitary and colonial corals, brachiopods, and gastropods. Excluding crinoid fragments, brachiopods are the most abundant and diverse megafossils in the Keel Formation (Amsden, 1974, p. 26). Maxwell reported *Zaphrentis subregularis* Savage (1913) (= *Streptelasma subregularis*) from the Ideal Quarry Member and *Streptelasma* sp. from the oölitic. The identity of these solitary corals is uncertain because specimens have not been located for sectioning.

Cape Girardeau County, Missouri

The Leemon Formation of southeastern Missouri is

up to 7 m thick. At the type section in Cape Girardeau County (Text-fig. 2, area No. 16; Text-fig. 21, locality 20a), the lower cross-bedded oölitic with Girardeau-type limestone pebbles and fine quartz grains is overlain by thickly-bedded, bioclastic and partly oölitic calcarenite (Thompson and Satterfield, 1975, pp. 76, 77; Amsden, 1974, p. 19). Except for abundant echinoderm debris, brachiopods dominate the megafauna. Solitary and colonial corals and gastropods are rare. The following solitary Rugosa are present in the upper part of the Leemon Formation at the type section: *Streptelasma leemonense* n. sp., *Streptelasma* sp., and *Bodophyllum shorti* n. sp. All corals were abraded and some were broken prior to burial (Pl. 4, figs. 1, 2, 4–6; Pl. 13, fig. 14). The only known specimen of *B. shorti* has a base of attachment on the cardinal side, and was epizoic on a bryozoan (Pl. 13, fig. 10).

The Leemon Formation is also exposed to the north at locality 20b (Thompson and Satterfield, 1975, pp. 79, 80; Amsden, 1974, pp. 21, 22; Text-fig. 21). Here, basal biohermal limestone mounds are up to 0.5 m high, with calcareous shale between and overlapping them. The mounds contain oöids (Pl. 4, figs. 11, 14, 15), glauconite, phosphatic material, quartz grains, and fossils in a calcareous matrix. The most abundant fossils are branching bryozoans, apparently preserved in life position. Some brachiopods are attached to and partly overgrown by bryozoans. Amsden (1974, p. 22) considered this brachiopod fauna the most characteristic Late Ordovician assemblage in the uppermost Ordovician sequences of Oklahoma and Missouri. Solitary Rugosa assigned to *Streptelasma subregularis* (Savage, 1913) are abundant at the base of some mounds. Specimens are randomly oriented and generally lie horizontally on an alar side, but calices of a small proportion face “down” or “up”. Although these corals have moderately dilated septa in early stages, they were apparently quite fragile because of the very narrow stereozones, open axial region, and very widely spaced tabulae (Pl. 4, figs. 9–22). Tips of many specimens were broken off and calice rims of some were broken before burial (Pl. 4, figs. 14, 15). However, all these corals have growth lines preserved, indicating no abrasion (Pl. 4, figs. 10, 11, 14, 15, 19). They may have been knocked over and buried suddenly, perhaps during a storm. The presence of *S. subregularis* at the base of the mounds suggests it may have been the initial species to colonize the eroded surface of the Orchard Creek Shale. The corals are not associated with and did not form a framework structure, and were not hosts of epizoic or boring organisms.

Pike County, Missouri

The Noix Limestone is exposed in eastern Pike County (Text-fig. 2, area No. 17). It is massive and cross-bedded, and consists of oöids in a micritic matrix. Glauconite and phosphatic grains are present in the lower part (Thompson and Satterfield, 1975, pp. 85–93; Amsden, 1974, pp. 8, 9). At the type section (Text-fig. 21, locality 21*b*), Thompson and Satterfield (1975, fig. 12) placed their bed 9, bounded by shale interbeds at its base and top, in the 2 m thick Noix Limestone. It did not yield conodonts, and was presumably included because it contains oöids. Solitary corals of the same species that is abundant at the base of their bed 10 (Kissenger Limestone Member of the Silurian Bryant Knob Formation) are present in bed 9, which is herein placed at the base of the Kissenger Member. The oöids were probably reworked from the Noix Limestone. The Noix fauna in Pike County has been listed by Rowley (1908, p. 23), and by Savage (1917*a*, pp. 82, 83), who also described new species. Rubey (1952, p. 170) listed the fauna in adjacent Calhoun County, Illinois. Echinoderm debris is generally abundant. Brachiopods dominate the remainder of the megafauna, with bryozoans, trilobites, gastropods, pelecypods, corals, and tentaculitids making up a small fraction of the assemblage (Amsden, 1974, p. 12). Although solitary corals have been listed from the Noix Limestone, none were found at localities 21*a* and 21*b* (Text-fig. 21).

To the west of the Noix Limestone belt, the Cyrene Formation is present in the vicinity of Edgewood, Cyrene, and Bowling Green in Pike County (Thompson and Satterfield, 1975, pp. 93–97, fig. 11). It is about 2 m thick at Bowling Green and consists of fine- to medium-grained, fossiliferous, dolomitic limestone (Text-fig. 21). The Cyrene fauna near Edgewood was listed by Savage (1917*a*, pp. 82, 83), who considered it very similar to that of the Noix Limestone. Conodonts of the Cyrene also occur in the Maquoketa Shale (Thompson and Satterfield, 1975, p. 96). Thompson and Satterfield (1975, p. 103) concluded that Cyrene strata were being deposited in the west while the Noix Limestone formed to the east. The solitary coral *Streptelasma subregulare* (Savage, 1913) is present in the Cyrene Formation. On the basis of this occurrence, the Cyrene is correlated with the Leemon Formation at locality 20*b* in southeastern Missouri.

Will County, Illinois

Savage (1910) discussed the Channahon Limestone in Will County (Text-fig. 2, area No. 18) and listed and described the fauna, which is dominated by brachiopods (Savage, 1917*a*, pp. 84–86). The Wilhelmi For-

mation of Willman (1973, pp. 12–14), which includes the Channahon, is up to 30 m thick in some channels but is absent or very thin between them. This formation comprises the very argillaceous dolomite and dolomitic shale of the Schweizer Member and the argillaceous dolomite of the overlying Birds Member (Text-fig. 21). A few thin, fossiliferous beds occur in the Schweizer Member, and some of the purer beds in the Birds Member are fossiliferous. C. A. Ross (1962) described graptolites suggesting an early Llandovery (Early Silurian) age from 0.5 m below the lowest occurrence of a shelly fauna in the Wilhelmi Formation. The solitary coral *Streptelasma subregulare* (Savage, 1913), collected by Savage from the Channahon Limestone, occurs with this shelly fauna. Its presence indicates correlation of the Wilhelmi with the Cyrene Formation of northeastern Missouri and the Leemon Formation at locality 20*b* in southeastern Missouri. The Wilhelmi Formation is herein considered latest Ordovician in age. The overlying Elwood Formation is cherty (Willman, 1973, pp. 14, 15), as is the Lower Silurian Sexton Creek Limestone of southeastern Missouri and southern Illinois. Silicified corals are common in the Elwood, and in the Lower Silurian Bryant Knob Formation of northeastern Missouri, and the basal Brassfield Formation near Gallatin, Tennessee.

CONTINENTAL MARGIN

Introduction

More than 1000 m of highly variable clastic rocks of Ashgill age that were deposited north of the Taconic Mountains at the continental margin of North America are exposed in northern Maine (Text-fig. 2, area No. 19, 20). The sequence indicates rapidly changing local tectonic controls (R. B. Neuman, 1968, p. 45). These clastic rocks grade northward into carbonates. The calcareous strata of the White Head Formation on the Gaspé Peninsula of Québec (Text-fig. 2, area No. 21) are Ashgill (Late Ordovician) and Llandovery (Early Silurian) in age. This sequence represents deposition in a more stable environment through a long period of time (R. B. Neuman, 1968, p. 45). On Anticosti Island, Québec (Text-fig. 2, area No. 22), the Upper Ordovician is more than 1000 m thick at some locations, and consists of interbedded limestones and shales of the Vauréal Formation and overlying Ellis Bay Formation. Twenhofel (1928, pp. 18–21) considered the lithology, sedimentary structures, and fauna to indicate a shallow marine environment, and believed the clastic sediments were derived from the north. Nowlan and Barnes (1981, p. 3) concluded that the lower Vauréal was deposited in relatively unstable, deep subtidal

conditions, and the upper Vauréal in progressively shallower subtidal environments. Within the Ellis Bay Formation, McCracken and Barnes (1981, p. 66) recognized a lateral transition from near-shore deposits in the east to offshore, shallow subtidal in the west. The general upward increase in carbonate content and faunal diversity and abundance, and the presence of stromatoporoid-colonial coral bioherms toward the top of the Anticosti sequence indicate a general shallowing-upward trend accompanied by increased productivity. This is also suggested by the frequency of microscopic algal borings observed in thin sections of solitary corals. These borings are present in 16 percent of 19 specimens from the Vauréal Formation, and 45 percent of 40 from the overlying Ellis Bay Formation. Sedimentary cycles in the upper portion of the generally regressive sequence on Anticosti Island have been attributed to eustatic sea-level fluctuations accompanying Late Ordovician glaciation (Petryk, 1981b). The greater thickness of continental margin marine deposits compared with those in the epicontinental sea (Richmond and Maquoketa Groups) is probably largely the result of more rapid subsidence. Also, sedimentation appears to have been continuous at the continental margin during latest Ordovician time, whereas a period of non-deposition and (or) erosion occurred in the interior. The Hirnantian strata of Gaspé and possibly northern Maine, and the Ellis Bay Formation (Gamachian) of Anticosti Island were deposited during this interval.

Penobscot County, Maine

More than 1000 m of Ashgill strata, including large amounts of coarse, bouldery, polymict conglomerate, pebbly siltstone, and other clastic rocks, are present in Penobscot County (R. B. Neuman, 1978, pers. comm.; Text-fig. 2, area No. 19; Text-fig. 22). The age assignment was made on the basis of brachiopods and trilobites. Colonial and solitary corals and gastropods are also present in the sequence (R. B. Neuman, 1968, pp. 44, 45). The assemblage and relatively high diversity of genera more closely resemble faunas of Europe than those elsewhere in North America (R. B. Neuman, 1968, p. 36). Solitary Rugosa in this clastic sequence are associated with carbonate debris and fossil fragments (Pl. 13, figs. 8, 9). The coral exteriors are generally abraded, but the preservation of septal grooves and interseptal ridges on some suggests that they may have been transported a short distance from a nearby carbonate bank. *Kenophyllum?* sp. is rare 61 m above the base of the sequence. Solitary corals are more common 520 m above the base, where *Strept-*

lasma rankini n. sp., *Grewingkia penobscotensis* n. sp., and *Bodophyllum neumani* n. sp. occur.

Ashland, Maine

R. B. Neuman (1963) reported tuffaceous mudstone, basalt-limestone conglomerate, and other clastic rocks in a 45 m thick unnamed unit exposed in a gravel pit 9 km east of Ashland, Maine (Text-fig. 2, area No. 20; Text-fig. 22). Brachiopods of north European affinity are by far the most common fossils in the sequence, followed in abundance by rugose and tabulate corals. Trilobites, gastropods, bryozoans, and graptolites are rare. The strata containing these fossils were deposited near the site of contemporaneous volcanism. Solitary Rugosa were found in bedrock exposures in the northeastern part of the gravel pit (R. B. Neuman, 1963, fig. 30.2). The abraded, apparently randomly oriented corals occur in mudstone containing abundant volcanic fragments. The only species known from this locality, *Grewingkia pulchella* (Billings, 1865), also occurs in the upper Vauréal and Ellis Bay Formations (Ashgill) of Anticosti Island, Québec. This indicates an Ashgill age for the unit at Ashland, and connection between the clastic and carbonate facies at the eastern continental margin.

Percé, Québec

The White Head Formation in the vicinity of Percé (Text-fig. 2, area No. 21) is Ashgill and Llandovery in age (Lespérance, Sheehan, and Skidmore, 1981). Its faunas in general are similar to those of Europe (Schuchert and Cooper, 1930, p. 170; Cooper and Kindle, 1936, p. 349; Lespérance, 1968a, p. 812; Sheehan and Lespérance, 1979, pp. 951, 952). Foerste (1936, p. 373) studied the Ordovician cephalopods, and suggested that they are most closely related to those in the Richmondian of the North American continental interior. The affinity of most conodonts is with the Midcontinent Province, but a few North Atlantic Province taxa are present (Nowlan, 1981, p. 274). F. Martin (1980) described chitinozoan and acritarch species that are also known from the central United States, eastern Canada, and northwestern Europe.

The White Head Formation is exposed in a belt that extends about 13 km northwest of the type section at Cap Blanc. The Ordovician portion locally exceeds 400 m in thickness, and has been subdivided into five lithologic units, numbered in ascending order (Skidmore and Lespérance, 1981, pp. 31, 33, figs. 25, 26; Text-fig. 22). The limestones, shales, and sandstones of units 1 to 4 are early to middle Ashgill in age (Lespérance, Sheehan, and Skidmore, 1981, p. 225, fig. 2;

Nowlan, 1981, pp. 265, 266, fig. 6). The distribution of fossils in these units has been summarized by Lespérance, Sheehan, and Skidmore (1981, p. 225). Unit 5 consists of calcareous mudstones, and contains the typical brachiopod-dominated *Hirnantia* fauna (Lespérance, 1974; Lespérance and Sheehan, 1976, 1981). Most species identified from the Percé area also occur in the Hirnantian Stage of the Ashgill Series in northern Europe, and the fauna is most closely related to that of Great Britain and Ireland (Lespérance and Sheehan, 1976, pp. 721, 722). Bolton (1980, p. 18, pl. 2.7, figs. 2, 3) illustrated solitary corals assigned to *Lobocorallium trilobatum vaurealense* (Twenhofel, 1928) that were collected from unit 4 on Flynn road, 32 m below the base of the Hirnantian. This species is associated with bryozoans and the colonial corals *Paleofavosites*, *Propora*, and *Catenipora*. Correlation with the upper part of the Vauréal Formation on Anticosti Island is suggested by the presence of *L. trilobatum vaurealense* in both units (see discussion under "Anticosti Island, Québec"). Nowlan (1981, p. 266, fig. 6) assigned the conodonts of unit 4 to Fauna 13 (McCracken and Barnes, 1981), indicating correlation with the Ellis Bay Formation of Anticosti Island. However, *Gamachignathus*, which characterizes the fauna, occurs in the upper Vauréal as well as in the Ellis Bay (Nowlan and Barnes, 1981, p. 5). Solitary Rugosa are not known from units 1 to 3 and 5 of the White Head Formation.

In the Percé area, Upper Ordovician sedimentary rocks also occur in fault slices to the north of the belt that is laterally continuous with the type section of the White Head Formation (Skidmore and Lespérance, 1981, fig. 25). These strata have been assigned to the undivided Matapédia Group by Lespérance, Sheehan, and Skidmore (1981, p. 223), but earlier workers included them in the White Head. At Grande Coupe, the solitary corals *Helicelasma selectum* (Billings, 1865), *Grewingkia* sp., *Lobocorallium trilobatum vaurealense*, and *Bodophyllum?* sp. are associated with a diverse fauna including the colonial genera *Paleofavosites*, *Catenipora*, *Propora*, and *Calapoecia*, as well as bryozoans, gastropods, cephalopods, brachiopods, and trilobites (Schuchert and Cooper, 1930, p. 169; Cooper and Kindle, 1936, p. 350; Bolton, 1980, pp. 16, 18, pl. 2.4, fig. 4, pl. 2.5, figs. 9, 10). Trilobites are the most abundant fossils, and suggest an early to middle Ashgill age for this *Stenoporeia* fauna (Lespérance, 1968a, pp. 813, 815, table 1). All the solitary corals were abraded and some were broken prior to final burial (Pl. 6, fig. 18). The single specimen of *Bodophyllum?* sp. examined in this study has an area of

attachment on the cardinal side, and was epizoic on a brachiopod (Pl. 14, figs. 7–9). Borings assigned to *Trypanites weisei* are common, and are abundant in the cardinal side of a specimen of *Grewingkia* sp. (USNM 311638). Of 94 borings in three solitary corals, 27 percent are in the counter side, 23 percent in an alar side, and 50 percent in the cardinal side. The frequency distribution of bore diameters is shown in Text-figure 9C. The average diameter is smaller than that of borings assigned to *T. weisei* in the Richmond Group of the Cincinnati Arch region and the Selkirk Member of the Red River Formation (upper Middle or Upper Ordovician) in southern Manitoba (Text-fig. 9A, B, D). Microscopic algal borings are present in corals from Grande Coupe, but are not well preserved. The presence of *L. trilobatum vaurealense* in these strata suggests correlation with unit 4 of the White Head Formation, and the upper part of the Vauréal Formation on Anticosti Island. *H. selectum* is also known from the upper member of the Vauréal, as well as the overlying Ellis Bay Formation (see discussion under "Anticosti Island, Québec").

Bolton (1980, p. 13) reported unidentified solitary corals from siltstones of the Honorat Group in southwestern Gaspé Peninsula.

Anticosti Island, Québec

Stratigraphy

The stratigraphic terminology used herein for Anticosti Island (Text-fig. 2, area No. 22; Text-fig. 22) follows Bolton (1972), unless specific reference is made to the units recognized by Twenhofel (1928). The recent lithostratigraphic revisions of Petryk (1981a) have not been incorporated into this study.

Approximately 300 m of the Vauréal Formation is exposed on the northern part of Anticosti Island, and the formation is at least 1000 m thick in a well drilled near the center of the island (Bolton, 1972, pp. 3, 5). The lower member of the Vauréal includes the portion of Twenhofel's English Head Formation that is exposed along the north shore. Outcrops of this member consist of gray shale and interbedded fine-grained to dense limestone plus intraformational limestone conglomerate. The limestone beds increase in thickness and become more nodular upward. The lower member continues in the subsurface, where the shale content increases downward in the section until a gray shale unit is distinguishable. The upper member of the Vauréal Formation includes, at or near its base, the western exposures and type section of Twenhofel's English Head Formation. This member is at least 180 m thick, and consists of gray, fine-grained to dense limestone

with abundant intraformational limestone conglomerate, fine cross-bedding and channel fills, and gray shale partings and lenses. Inland outcrops include thinly- to thickly-bedded dense to fine-grained limestone with shale interbeds and partings, and nodular limestone. Toward the top of the upper member, colonial coral-stromatoporoid bioherms are overlain by irregularly-bedded, dense to granular limestone with shale partings. The upper strata of the Vauréal are thinly-bedded, fine-grained to granular limestone with abundant intraformational limestone conglomerate, and thin interbeds or lenses of dense to semilithographic limestone with argillaceous partings. The uppermost beds are argillaceous nodular limestone.

In his discussion of the English Head Formation, Twenhofel (1928, p. 31) noted that brachiopods are dominant and gastropods plentiful. He stated that rugose corals are rare compared to tabulates, and listed and described the diverse fauna. On the basis of the fauna and distribution of some species, Twenhofel (1928, pp. 63, 64) correlated the English Head with the "Waynesville" of the Richmond Group in the Cincinnati Arch region. Sinclair (1956, p. 1734) considered the English Head to be slightly older, equivalent to "some part of the Covington of Ohio and the Lorraine of New York and southern Québec." Bolton (1972, p. 8) noted that several genera in this interval are apparently confined to the Richmondian. Twenhofel (1928, p. 31) observed a greater abundance of corals higher in the section (his Vauréal Formation), and listed and described the large fauna. On the basis of this fauna and the vertical distribution of some species, Twenhofel (1928, p. 65) correlated his Vauréal with the "Liberty" through "Elkhorn" of the Richmond Group.

In the lower gray shale unit of the subsurface Vauréal Formation, as it is presently defined, Jansonius (1967, p. 357) recorded early to middle Caradoc chitinozoans. The graptolites (Riva, 1969) and trilobites (Bolton, 1970) indicate a Lorraine-Ashgill-Harjuan age. Most of the lower member of the Vauréal was placed in the *Dicellograptus complanatus* zone by Riva (1969, p. 550, fig. 16). Chitinozoans in this zone were considered to be upper Caradoc-lower Ashgill by Achab (1977a). Riva (1969, pp. 550, 551, fig. 16) placed the upper member of the Vauréal in the *Climacograptus prominens-elongatus* (= *Amplexograptus inuiti*; see Riva and Petryk, 1981, p. 160) zone, which was considered to be post-Ashgill but pre-Llandovery in age. These strata contain late Caradoc chitinozoans according to Jansonius (1967, p. 357). Achab (1977b) noted that the chitinozoans are distinctive and have not been reported elsewhere. A sparse Upper

Ordovician microfauna of ostracodes and a foraminifer was described from the exposed portion of the Vauréal Formation by Copeland (1970). Nowlan and Barnes (1981, p. 5) determined that conodonts of the exposed Vauréal are predominantly characteristic of Fauna 12 (Sweet, Ethington, and Barnes, 1971), which is late Maysvillian-Richmondian, although some range down into Fauna 11. They also noted that the presence of *Gamachignathus* may indicate a latest Ordovician (Gamachian) age for the upper part of the Vauréal.

The Vauréal Formation is conformably overlain by the Ellis Bay Formation, which is 50 to 95 m thick (Bolton, 1961, p. 6). It consists of gray shale with argillaceous limestone, and units of interbedded limestone and shale. Six members were described by Bolton (1972, p. 8). Near the base of member 6, bioherms containing abundant colonial corals are up to 110 m long and 5 m high. The contact with the overlying Llandovery (Lower Silurian) Becscie Formation is difficult to define because of the very gradual lithologic transition. Twenhofel (1928, p. 32) noted that the Ellis Bay fauna is more diverse and abundant than that in his Vauréal and English Head Formations, and contains almost 25 percent of the species in these earlier units as well as many new forms. He reported that brachiopods are the most abundant faunal element, and corals are more common than in his Vauréal and English Head. The fauna has a decided Richmondian aspect, but some species suggest a Silurian age (Twenhofel, 1928, pp. 68, 69). Schuchert and Twenhofel (1910, pp. 700, 701) proposed the Gamachian Stage to include the Ellis Bay Formation and all American strata later in age than the youngest Richmondian of Ohio and Indiana but below clearly recognizable Silurian strata (Twenhofel, 1914, p. 8; 1928, pp. 35, 36).

J. P. Ross (1960, pp. 1060, 1061) found that many bryozoans of the Vauréal and Ellis Bay Formations are closely related to those in the Richmond Group of Ohio and Maquoketa Group of Iowa, and did not support the concept of a Gamachian Stage. Lespérance (1968b, pp. 151-153) noted a definite close correspondence among trilobites of the Richmond Group, the Ellis Bay Formation, and the early to middle Ashgill *Remipyga* (= *Ceraurinus icarus*; see Lespérance, Sheehan, and Skidmore, 1981, p. 224) fauna within the White Head Formation at Percé, Québec. Riva (1969, p. 553) interpreted the Ellis Bay graptolites as being post-Ashgill but pre-Llandovery in age. Boucot (in Ayrton *et al.*, 1969, p. 462) considered the formation to be of early Llandovery age on the basis of two brachiopod species. Bolton (1972, table 1) placed it in the Richmondian. Almost half of the Ellis Bay ostracode species also occur in the Vauréal (Copeland,

1973, p. 7), and this Ordovician assemblage has been traced to about 10 m below the top of the Ellis Bay Formation. Although many conodont taxa from the Vauréal Formation are present in the lower Ellis Bay, McCracken and Barnes (1981, p. 64) recognized *Gamachignathus* as characteristic. Fauna 13 was proposed for this assemblage and considered Gamachian in age. The Ordovician-Silurian boundary was placed at the first appearance of *Ozarkodina* about 2 to 3 m above the base of member 6 within the Ellis Bay Formation. Duffield and Legault (1981) suggested that a significant change in acritarch assemblages occurs at or near this horizon. Riva and Petryk (1981) studied the graptolites and concluded that the systemic boundary is located within a narrow interval represented by the bioherms of member 6 and the overlying 1 or 2 m of strata. Cocks and Copper (1981) assigned most of the Ellis Bay Formation to the Rawtheyan Stage of Europe on the basis of brachiopods. They reported an *Hirnantia* fauna near the top of the formation, indicating that the Hirnantian Stage of Europe is equivalent to the upper part of the Gamachian.

Eight species of solitary corals are recognized from the Vauréal and Ellis Bay Formations (Text-fig. 22). *Streptelasma affine* (Billings, 1865) occurs in the lower and upper members of the Vauréal Formation and in the Ellis Bay Formation. *Bighornia* cf. *B. patella* (A. E. Wilson, 1926) is found in the lower member of the Vauréal. *Grewinkia pulchella* (Billings, 1865) and *Helicelasma selectum* (Billings, 1865) are present from the base of the upper member of the Vauréal Formation, through the Ellis Bay Formation. *Bodophyllum englishheadense* n. sp. occurs at the base of the upper member of the Vauréal. *Lobocorallium trilobatum vaurealense* (Twenhofel, 1928) and *Deiracorallium angulatum* (Billings, 1862) are known from the upper part of the upper member of the Vauréal Formation. *Paliphyllum ellisense* (Twenhofel, 1928) is present in the Ellis Bay Formation.

Lobocorallium trilobatum vaurealense and *Helicelasma selectum* both occur in the upper member of the Vauréal Formation and in the early to middle Ashgill *Stenopareia* faunal zone of the White Head Formation at Percé, suggesting correlation of these units (Text-fig. 22). *L. trilobatum vaurealense* is also known from unit 4 (middle Ashgill) of the White Head. The range of *H. selectum* extends through the Ellis Bay Formation on Anticosti Island. The presence of *L. trilobatum vaurealense* and *Deiracorallium angulatum* in the upper Vauréal Formation and the former in the early to middle Ashgill of the White Head Formation suggests correlation of these strata with the Stony Mountain Formation in southern Manitoba. *L.*

trilobatum trilobatum (Whiteaves, 1895) and a form of *Deiracorallium* very close to *D. angulatum* occur in the Gunn and Penitentiary Members of the Stony Mountain Formation. Twenhofel (1928, pp. 66, 67) considered the fauna in his zones 3 to 5 of the Vauréal Formation to indicate fairly positive correlation with the Stony Mountain. The lower member of the Vauréal and the Red River Formation of southern Manitoba (which underlies the Stony Mountain) may be Caradoc in age. *Bighornia* cf. *B. patella* occurs in both units, but is widespread geographically and stratigraphically (see "Systematic Paleontology").

Three of the six solitary coral species in the upper member of the Vauréal Formation extend through the Ellis Bay Formation, indicating that the latter unit is Ordovician in age. *Streptelasma affine*, which is common in the Ellis Bay, most closely resembles *S. primum* (Wedekind, 1927) from the Ashgill Division 5a of Norway and Boda Limestone of Sweden. It is similar to *S. subregulare* (Savage, 1913) of the uppermost Ordovician (?Gamachian) in Missouri and Illinois, and *S. unicum* B. Neuman (1975), probably from the Hirnantian *Dalmanitina* beds of Sweden. *Paliphyllum ellisense* represents a genus found in member No. 3 of the Chasm Creek Formation, Churchill River Group, northern Manitoba, which correlates with the upper Stony Mountain Formation of southern Manitoba (Nelson, 1963, fig. 2). *Paliphyllum* is also known from the Upper Ordovician of Sweden, Estonia, and Siberia, and the Llandovery (Lower Silurian) of Ohio and Estonia. The proposed location of the Ordovician-Silurian boundary within member 6 of the Ellis Bay Formation (McCracken and Barnes, 1981; Duffield and Legault, 1981; Riva and Petryk, 1981) cannot be evaluated on the basis of solitary Rugosa at this time because the exact stratigraphic position of available specimens from that member is not known.

Solitary Rugose Corals

Streptelasma affine (Billings, 1865) occurs in the Vauréal Formation, and is common in the Ellis Bay Formation. Bolton (1981, p. 107) reported the species in bioherms within member 6 of the Ellis Bay. Specimens examined in this study show little evidence of pre-depositional abrasion, and apparently lived in low energy environments (Pl. 5, figs. 4, 5, 9). They are ceratoid to trochoid and slightly to moderately curved in early ontogenetic stages, becoming cylindrical and usually straight in late stages (Pl. 5, figs. 10, 14). Some corals have talons in early stages (Pl. 5, figs. 9, 10). Very large specimens have been collected in the upper Vauréal Formation (GSC 1987), and in Twenhofel's (1928) zones 5 (YPM 28705) and 9 (YPM 28709) of the

Ellis Bay Formation. Epizoans are fairly common on these corals (Pl. 5, fig. 9). In the Vauréal, they include stromatoporoids, bryozoans, and colonial corals. In Twenhofel's zone 5 of the Ellis Bay, epizoic bryozoans, stromatoporoids, and cornulitids occur, and in his zones 7 and 9, bryozoans and stromatoporoids are present. Coarse rugae are regularly spaced on some corals in the lower Vauréal and in Twenhofel's zones 5 and 9 of the Ellis Bay (Pl. 5, fig. 9). The size and growth form of this species and the abundance and diversity of associated epizoans suggest that environmental conditions were stable and very favorable for organisms during deposition of the Vauréal Formation and Twenhofel's zones 5 and 9 of the Ellis Bay Formation. Borings assigned to *Trypanites weisei* are present in only two of 29 specimens of *S. affine*. Microscopic algal borings have been observed in eight of 16 corals for which thin sections were examined. Those seen in one specimen (YPM 28686) are considered to be Holocene in age because they penetrate secondary calcite crystals.

Helicelasma selectum (Billings, 1865) is uncommon in Twenhofel's collection. Almost all specimens were abraded prior to final burial, indicating transportation in relatively high energy conditions (Pl. 6, fig. 12). They occur in argillaceous calcilitites and calcarenites. Epizoans were not observed. Borings assigned to *Trypanites weisei* are present in one of ten corals. Microscopic algal borings were observed in four of five specimens for which thin sections were examined.

Specimens of *Deiracorallium angulatum* (Billings, 1862) are well preserved and were not abraded prior to final burial, indicating that they lived in very low energy conditions (Pl. 6, figs. 21, 22, 25, 26). The species seems to be generally sparse, but is quite abundant in argillaceous limestones of the Potatoe River area (T. E. Bolton, 1977, pers. comm.). Epizoans and borings are not present on the 33 specimens examined.

On the basis of available collections, *Grewingkia pulchella* (Billings, 1865) appears to be the most abundant Ordovician solitary coral on Anticosti Island. Specimens are generally not abraded, and presumably lived in low energy environments (Pl. 12, figs. 7, 8, 11, 15). They occur in argillaceous limestones in association with bryozoans and brachiopods. One specimen (YPM 28757) was collected in a bioherm within the Ellis Bay Formation. The length-frequency histogram based on Twenhofel's collection is unimodal, but it is not known if his sample accurately reflects the population (Text-fig. 23). Only one of more than 100 individuals of *G. pulchella* has epizoic bryozoans. Borings assigned to *Trypanites weisei* are not present. Micro-

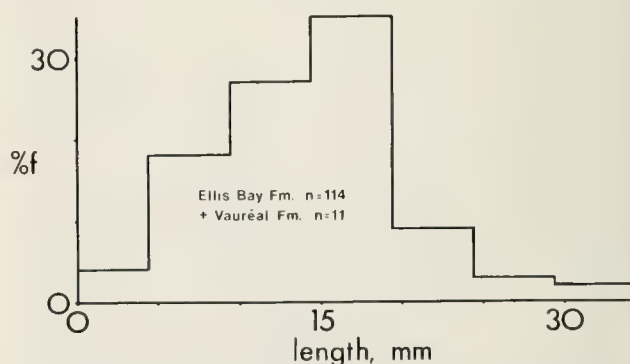
scopic algal borings were observed in ten of 19 specimens for which thin sections were examined.

Lobocorallium trilobatum vaurealense (Twenhofel, 1928) is rare in available collections. Bolton (1981, p. 107) reported the species in bioherms within the Vauréal Formation. These large, trilobate corals were abraded in relatively high energy conditions prior to burial (Pl. 13, fig. 1s). One specimen (YPM 20482) occurs in argillaceous limestone with abundant brachiopods, bryozoans, and arthropod fragments. At GSC locality 36157, this species is present in coarse-grained calcarenite. Epizoans and boring algae are not associated with the specimens that were examined, but one has abundant borings assigned to *Trypanites weisei* (Pl. 13, fig. 1s).

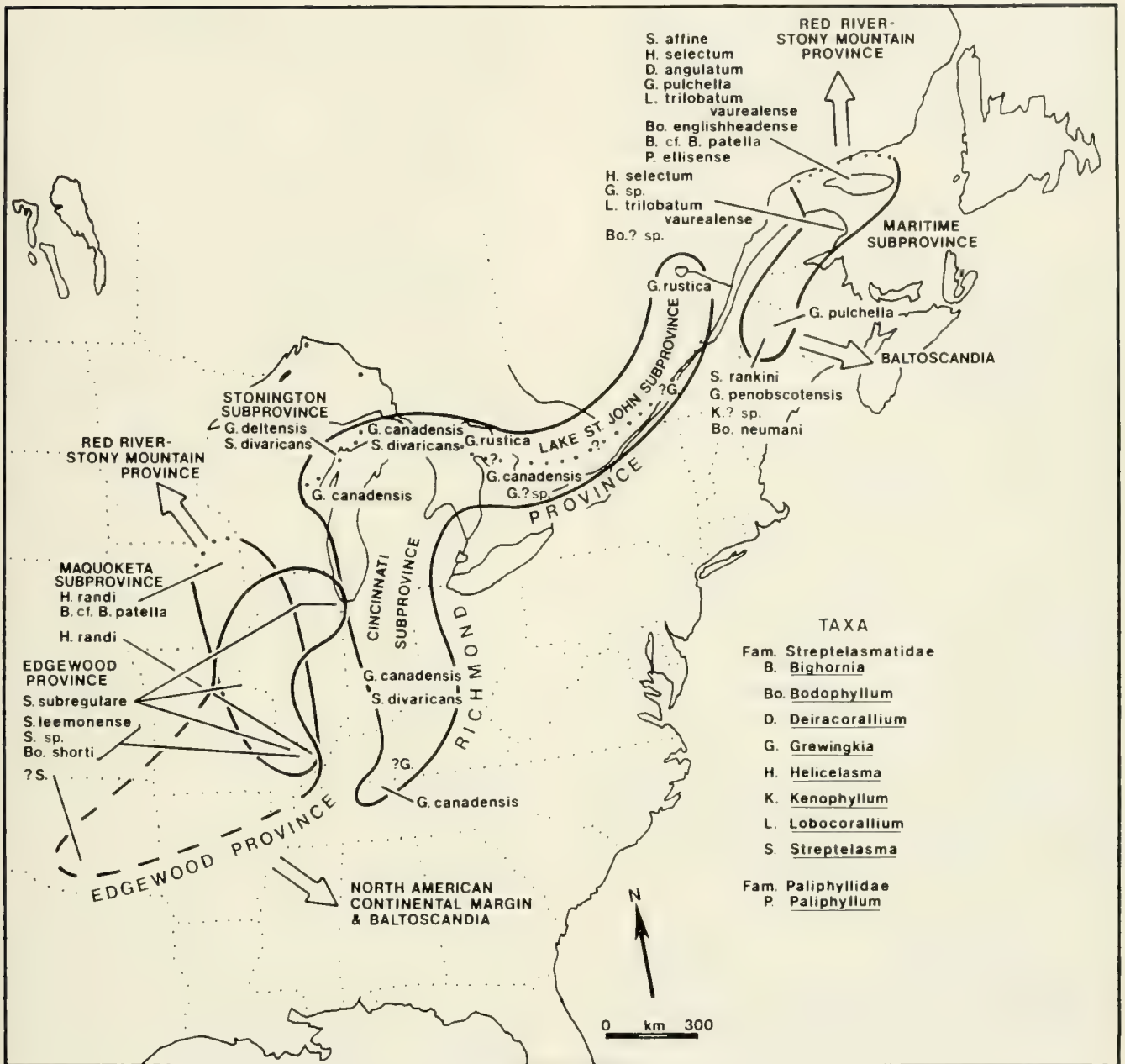
Bodophyllum englishheadense n. sp. is rare in Twenhofel's collection. These corals have a base of attachment centered on the cardinal side, and in one specimen are epizoic on a bryozoan (Pl. 14, figs. 11, 14). All were abraded before burial, indicating relatively high energy conditions. Two specimens (YPM 28767, 28768) occur in calcilitite with brachiopods and arthropod fragments, and two others (YPM 28765, 28766) are in echinodermal calcarenite. Epizoans and borings are not present on the five corals examined.

Bighornia cf. *B. patella* (A. E. Wilson, 1926) is rare in Twenhofel's collection. All specimens have a spoon-shaped area of attachment on the concave cardinal side near the tip (Pl. 15, fig. 7). These corals were not abraded before burial, suggesting that they lived in low energy environments. Epizoans and borings are not present.

Paliphyllum ellisense (Twenhofel, 1928) is uncommon in Twenhofel's collection. Several of the specimens were collected from an Ellis Bay bioherm (YPM 28777, 28778). A few were slightly abraded before burial. The corals are cylindrical and some have regularly



Text-figure 23.—Length of specimens of *Grewingkia pulchella* (Billings, 1865) from the Vauréal and Ellis Bay Formations, Anticosti Island, Québec. %f = percent frequency. n = number of specimens.



Text-figure 24.—Paleobiogeography of latest Ordovician solitary rugose corals in eastern North America.

spaced coarse rugae (Pl. 15, fig. 20). This species probably lived in a fairly low energy, stable environment. Epizoid bryozoans were observed on five of 26 specimens. Borings are not present.

PALEOBIOGEOGRAPHY OF LATEST ORDOVICIAN SOLITARY RUGOSE CORALS IN EASTERN NORTH AMERICA

OVERVIEW

Latest Ordovician (Richmondian and Gamachian; Ashgill) solitary Rugosa of eastern North America are

assigned to three provinces that are distinguished on the basis of assemblages and characteristic species (Table 3; Text-fig. 24). The distribution of these solitary coral provinces corresponds closely to paleogeography and lithofacies (Text-fig. 2). The Richmond Province coincides with the Richmond Group. Solitary corals of the Maquoketa Group and those at the eastern continental margin belong to the Red River-Stony Mountain Province. Those in the uppermost Ordovician carbonate sequence of Oklahoma, Missouri, and Illinois are assigned to the Edgewood Province. The late Middle (?) through Late Ordovician Red River-

Stony Mountain Province is by far the most extensive in space and time. The geographic and stratigraphic distribution of taxa within these provinces was determined by regional environmental parameters related to paleogeography.

RED RIVER-STONY MOUNTAIN PROVINCE

Introduction

The Red River-Stony Mountain Province extends from western Texas and New Mexico through west-central North America to Alaska, northern Greenland, and the Maritimes (Elias, 1981, pp. 2, 8, 10). The vast continental interior portion was occupied by shallow, interconnected epicontinental seas centralized in large areas of subsidence such as the Williston and Hudson Basins. Remarkably similar massive carbonate deposits formed throughout the area, indicating widespread, stable, uniform environmental conditions (Flower, 1965, fig. 5). The epicontinental seas are thought to have been characterized by higher than normal temperature and salinity (Barnes and Fähræus, 1975). Carbonate and clastic sediments were deposited in normal Ordovician open marine environments at the continental margin.

The Red River-Stony Mountain Province is characterized by corals having unusual external form. *Grewingkia* includes species that are triangulate and trilobate in cross-section. *Deiracorallium* and *Lobocorallium* are compressed and trilobate, respectively. *Bighornia* is distinct in having the cardinal septum on the concave side of the depressed coral. Diversity in carbonate facies within the Red River-Stony Mountain Province is generally high.

Maquoketa Subprovince

The Maquoketa Subprovince (upper Mississippi valley) is characterized by the paucity and very low diversity of solitary corals in carbonate beds within the Maquoketa Group, which is predominantly shale (Table 3; Text-fig. 24). *Helicelasma randi* Elias (1981) occurs in northeastern Iowa, northwestern Illinois, and southwestern Illinois. It is also present in the Selkirk Member of the Red River Formation (upper Middle or Upper Ordovician) in southern Manitoba. Within the Maquoketa Subprovince, *Bighornia* cf. *B. patella* (A. E. Wilson, 1926) is known only from the Fort Atkinson Formation in northeastern Iowa. This species also occurs in the Red River and Stony Mountain Formations of southern Manitoba, and at other localities in the Red River-Stony Mountain Province (see "Systematic Paleontology"). The presence of identical species on both sides of the Transcontinental Arch indicates that migration across this slightly pos-

Table 3.—Latest Ordovician solitary rugose corals in paleobiogeographic provinces and subprovinces, eastern North America.

Red River-Stony Mountain Province

Maquoketa Subprovince

Helicelasma randi Elias (1981)
Bighornia cf. *B. patella* (A. E. Wilson, 1926)

Maritime Subprovince

Streptelasma rankini n. sp.
S. affine (Billings, 1865)
Helicelasma selectum (Billings, 1865)
Deiracorallium angulatum (Billings, 1862)
Grewingkia penobscotensis n. sp.
G. pulchella (Billings, 1865)
Grewingkia sp.
Lobocorallium trilobatum vaurealense (Twenhofel, 1928)
Kenophyllum? sp.
Bodophyllum neumani n. sp.
Bodophyllum? sp.
B. englishheadense n. sp.
Bighornia cf. *B. patella* (A. E. Wilson, 1926)
Paliphyllum ellisense (Twenhofel, 1928)

Richmond Province

Cincinnati Subprovince

Streptelasma divaricans (Nicholson, 1875b)
Grewingkia canadensis (Billings, 1862)

Stonington Subprovince

Streptelasma divaricans (Nicholson, 1875b)
Grewingkia deliensis n. sp.

Lake St. John Subprovince

Grewingkia rustica (Billings, 1858a)

Edgewood Province

Streptelasma leemonense n. sp.
Streptelasma sp.
S. subregulare (Savage, 1913)
Bodophyllum shorti n. sp.

itive structure took place at least periodically during the late Middle (?) to Late Ordovician. *H. randi* and *B. cf. B. patella* became extinct in the Maquoketa Subprovince when the eastern North American epicontinental sea withdrew at the end of the Richmondian.

Maritime Subprovince

A diverse assemblage of solitary corals occurs on the continental margin at Anticosti Island and Percé, Québec, and northern Maine (Table 3; Text-fig. 24). *Bighornia* cf. *B. patella* (A. E. Wilson, 1926), a Red River-Stony Mountain species of wide geographic and considerable stratigraphic range, occurs with *Streptelasma affine* (Billings, 1865) in the lower member of the Vauréal Formation on Anticosti Island. *Deiracorallium angulatum* (Billings, 1862) of the upper member is very similar to a form in the Stony Mountain Formation of southern Manitoba and the correlative

Churchill River Group of northern Manitoba. *Lobocorallium trilobatum vaurealense* (Twenhofel, 1928) is very close to *L. trilobatum trilobatum* (Whiteaves, 1895) of the Stony Mountain Formation. Also present in the upper member of the Vauréal Formation are *S. affine*, *Helicelasma selectum* (Billings, 1865), *Grewingkia pulchella* (Billings, 1865), and *Bodophyllum englishheadense* n. sp. In the vicinity of Percé, Québec, *L. trilobatum vaurealense* is known from unit 4 of the White Head Formation, and occurs with *H. selectum*, *Grewingkia* sp., and *Bodophyllum*? sp. in the *Stenopareia* faunal zone at Grande Coupe. *S. affine*, *H. selectum*, and *G. pulchella* of the Vauréal Formation extend into the Ellis Bay Formation on Anticosti Island. Also present in the Ellis Bay is *Paliphyllum elisense* (Twenhofel, 1928), representing a genus found within the Red River–Stony Mountain Province in northern Manitoba. *G. pulchella*, apparently the most abundant species on Anticosti Island, also occurs in the clastic facies near Ashland, Maine. In Penobscot County, Maine, *S. rankini* n. sp., *G. penobscotensis* n. sp., *Bodophyllum neumani* n. sp., and *Kenophyllum*? sp. are present in clastic rocks. Although the species are unique to this locality, the generic assemblage resembles that at Percé and Anticosti Island.

Presence of the characteristic genera *Lobocorallium*, *Deiracorallium*, and *Bighornia* indicates that the carbonate facies of the Anticosti–Percé region was deposited within the Red River–Stony Mountain Province. Equivalence of taxa at the species level, especially with southern Manitoba, suggests communication via the northern Canadian Shield during Late Ordovician time. Although taxa characteristic of the Red River–Stony Mountain Province are not known from Maine, the presence of *G. pulchella* at Anticosti Island and Ashland demonstrates that the carbonate and clastic facies were connected. In addition to the three genera listed above, *Grewingkia*, *Helicelasma*, and *Paliphyllum* are also represented at the margins and interior of the Red River–Stony Mountain Province. However, *Streptelasma* and *Bodophyllum* are unknown from the continental interior. The presence of these two genera and several species that are relatively widespread at the eastern continental margin of North America (*L. trilobatum vaurealense*, *H. selectum*, and *G. pulchella*) serve to distinguish the Maritime Subprovince.

Solitary corals of the Upper Ordovician Centrum Formation in northeastern Greenland were described by Scrutton (1975, pp. 15–17, pl. 2, figs. 1–5). *Streptelasma* sp. cf. *S. primum* and *Helicelasma* sp. A are similar to *S. affine* and *Grewingkia pulchella*, respectively, of the Maritime Subprovince. Red River

species of the continental interior occur in the Troedsson Cliff and Cape Calhoun Formations of northwestern Greenland (Elias, 1981, p. 10). A latest Ordovician generic assemblage similar to that of the Maritime Subprovince occurs in the eastern Great Basin (southwestern United States), where Budge (1977) reported *Lobocorallium*, *Deiracorallium*, *Bighornia*, *Streptelasma*, cf. *Grewingkia*, *Bodophyllum*, and “*Tryplasma*”. *Streptelasma*, *Grewingkia*, *Bodophyllum*, *Helicelasma*, *Tryplasma*, and *Paliphyllum* are also present in Baltoscandia (Table 4). It appears that solitary coral assemblages at the continental margin around North America are characterized by Red River–Stony Mountain species of the continental interior in association with genera (but not species) that also occur in Baltoscandia. This generic similarity probably reflects similar normal Ordovician open marine environments. Baltoscandian brachiopods (Sheehan, 1975; Sheehan and Lespérance, 1979) and conodonts (Barnes and Fähræus, 1975) are also present at the continental margin around North America.

The north European affinity of the eastern continental margin fauna has been emphasized repeatedly and used for biostratigraphic correlation. The brachiopod and trilobite assemblages in the two regions have many species in common (see discussions under “Penobscot County, Maine”, “Ashland, Maine”, and “Percé, Québec”). It is noteworthy that solitary rugose corals not restricted to the Maritime Subprovince are conspecific with or close to forms in the continental interior portion of the Red River–Stony Mountain Province. Because of this, correlations with European sections, based on brachiopods and trilobites, can be extended into the continental interior of North America using solitary corals. An early to middle Ashgill age is suggested for the Stony Mountain Formation in southern Manitoba, and the underlying Red River Formation may be of Caradoc age (see discussion under “Anticosti Island, Québec”).

RICHMOND PROVINCE

Introduction

The Richmond Province occupies a narrow belt extending northward from the Nashville Dome of Tennessee, along the Cincinnati Arch region of Kentucky, Indiana, and Ohio to northern Michigan, and eastward through southern Ontario and Québec (Table 3; Text-fig. 24). It coincided with a carbonate platform at the margin of an epicontinental sea that received clastic sediments from the Queenston delta (Ontario, New York, Pennsylvania, and Ohio). A great variety of environments was present, ranging from open waters of

Table 4.—Solitary rugose coral genera in the Ashgill of Scandinavia (compiled from B. Neuman, 1968, 1969, 1975). Division 5b and the *Dalmanitina* beds contain the characteristic *Hirnantia* fauna. The Boda Limestone, which consists of reef core and flank deposits, probably corresponds in part to the *Dalmanitina* facies. It does not contain the typical *Hirnantia* fauna, but more characteristic elements occur in increasingly shaly beds to the south (P. J. Lespérance, 1978, pers. comm.).

LOCATIONS	TAXA UNITS	Fam. Streptelasmataceae							Fam. Tryplasmataceae Tryplasma	Fam. Paliphyllidae Paliphyllum
		Streptelasma	Grewingkia	Bodophyllum	Helicelasma	Densigrewingkia	Borelasma	Ullernelasma		
Norway	Division 5b			X		X		X		
	Division 5a	X	X	X		X				
Sweden	<i>Dalmanitina</i> beds	X		X	X		X			
	Boda Limestone	X	X	X					X	X

the platform margin, where colonial coral banks developed, to restricted hypersaline lagoons. As would be expected in an area of clastic sedimentation, solitary coral diversity was very low. The genera *Grewingkia* and *Streptelasma* are represented by *G. canadensis* (Billings, 1862), *G. rustica* (Billings, 1858a), *G. deltensis* n. sp., and *S. divaricans* (Nicholson, 1875b). *G. canadensis* occurs in northern Tennessee, the Cincinnati Arch region, eastern Wisconsin, on Drummond Island, Michigan, Manitoulin Island, Ontario, and at Meaford, Ontario. *S. divaricans* is present in the Cincinnati Arch region, northern Michigan, and on Manitoulin Island. The relatively large central portion of the Richmond Province where *G. canadensis* and often *S. divaricans* are found is termed the Cincinnati Subprovince. What this assemblage lacks in taxonomic diversity is offset by great intraspecific variability. The number of septa at a particular coral diameter and the axial region are highly variable. At Little Bay de Noc in northern Michigan, *S. divaricans* and *G. deltensis* are present. The latter species is unique to this area, which is termed the Stonington Subprovince. *G. rustica* occurs at Lake St. John, Québec, and the single specimen found on Manitoulin Island was transported from an unknown source. The area of the Richmond Province occupied by *G. rustica*

is termed the Lake St. John Subprovince. Its exact boundary with the Cincinnati Subprovince is uncertain because corals in the vicinity of Montréal, Québec, and Streetsville, Ontario, have not been identified at the species level.

Origin

Solitary corals of the Richmond Province first appeared in carbonate beds at the base of "Waynesville" strata in the Richmond Group. Those in the lower Arnheim Formation of Tennessee may also be of "Waynesville" age. Solitary Rugosa are unknown in Upper Ordovician strata underlying the Richmond Group. They may have been introduced to this geographic region during an early Richmondian transgression. The source was probably to the west, where solitary corals are known from Edenian-Maysvillian strata of the Maquoketa Group. Those in the "Trentonian"—lower Cincinnati of Minnesota, described as *Streptelasma corniculum* Hall (1847) and *S. rusticum* (Billings, 1858a) in Winchell and Schuchert (1895, pp. 90, 91, 93, pl. G, figs. 20–23), resemble *Grewingkia canadensis* and *G. rustica* externally, and the "Trentonian" *S. (?) parasiticum* Ulrich (in Winchell and Schuchert, 1895, pp. 89, 90, fig. 6) is remarkably similar in growth form to *S. divaricans*. A detailed study

of solitary corals in the upper Middle–lower Upper Ordovician of eastern North America is required to determine if the Richmond Group contains recurrent Blackriveran–“Trentonian” forms (see Foerste, 1924, pp. 43–45).

Grewingkia canadensis and *G. rustica* are virtually identical externally. A single specimen of *G. rustica* was found on Manitoulin Island at the base of the Meaford beds, in which *G. canadensis* occurs. It had been transported from an unknown source, but suggests close relation in space and time between the two species. It is possible that both were derived from a common ancestor, or *G. rustica* may have arisen from *G. canadensis* in the eastern digitation of the Richmond Province by geographic speciation very soon after introduction from the west.

Grewingkia deltensis, which occurs within micritic limestone of the Ogontz Member of the Stonington Formation in northern Michigan, has the trochoid, moderately curved form and large size typical of species of *Grewingkia* within massive carbonates of the Selkirk Member of the Red River Formation (upper Middle or Upper Ordovician) in southern Manitoba (Elias, 1981). It is present in the digitation of the Richmond Province nearest Manitoba. Selkirk Member species of *Bighornia* and *Helicelasma* occur in the Maquoketa Group to the southwest, indicating that dispersal across the Transcontinental Arch was possible. *G. deltensis* may have arisen from Red River forms, but it was unable to migrate farther into the Richmond Province because suitable environments resulting in Ogontz-type deposition were not present elsewhere.

Subsequent History

Following introduction into the belt of Richmond Group sedimentation, solitary corals dispersed laterally as favorable environments became more widespread. They attained their maximum geographic range during “Liberty–early Whitewater” time. Migration out of and into the Richmond Province was restricted shoreward by the Queenston delta and Taconic upland, the positive Nashville Dome, and the Canadian Shield, which was probably slightly positive (Copper and Grawbarger, 1978, p. 1990; see discussion under “Meaford, Ontario”). Seaward of the carbonate platform, deeper water in which the Maquoketa Group shale was deposited proved to be an impenetrable barrier. Progradation of the Queenston delta eliminated corals from the Montréal, Streetsville, and Meaford areas of southern Québec and Ontario during Richmondian time. Extinction of Richmond Province

species resulted from withdrawal of the eastern North American epicontinental sea at the end of the Richmondian, possibly due to a glacioeustatic sea-level drop. Presence of the Richmond Group fauna in carbonate beds at the top of the Maquoketa shale at Little Sturgeon Bay, Wisconsin, may reflect this final westward retreat.

To account for the different assemblages in regions corresponding to the Red River–Stony Mountain and Richmond Provinces, Flower (1946, p. 127) and Nelson (1959a) suggested that the “Arctic Ordovician” (Red River–Stony Mountain) fauna of central North America was tropical in character, whereas the eastern (Richmond) fauna was temperate. This widely cited climatic influence need not be invoked, especially when it is seen that the Red River–Stony Mountain Province occurs on opposite sides and ends of the Richmond Province (Text-fig. 24). Paleogeography and the related type of sedimentation were the primary factors that determined the nature and extent of these faunas. Because species and assemblages of solitary corals (and many other faunal elements) in the two provinces are different, they cannot be used at present to correlate the North American Upper Ordovician type sections in the Cincinnati Arch region with strata outside the Richmond Province.

EDGEWOOD PROVINCE

The Edgewood Province coincides with the carbonate sequence deposited during a latest Ordovician (?Gamachian) transgression into the continental interior (Illinois, Missouri, and Oklahoma) (Table 3; Text-fig. 24). Normal Ordovician open marine environments are indicated by the development of oölite shoals and small bioherms. As would be expected in such environments, the solitary corals (and brachiopods) resemble those that previously occurred only at the continental margin, and are different from those of the continental interior Red River–Stony Mountain and Richmond Provinces. *Streptelasma subregulare* (Savage, 1913) of northeastern Illinois and northeastern and southeastern Missouri is the most widely distributed solitary coral in this province. It is similar to *S. affine* (Billings, 1865) of Anticosti Island, and most closely resembles *S. unicum* B. Neuman (1975) of Sweden. *S. leemonense* n. sp., *Streptelasma* sp., and *Bodophyllum shorti* n. sp. are present in southeastern Missouri. *B. shorti* is the only representative of the genus known from the continental interior of North America. *S. subregulare* and *Streptelasma* sp. have been reported from the Arbuckle Mountains (Maxwell, 1936), but these identifications require confir-

mation. Extension of the Edgewood Province into Oklahoma is therefore tentative.

The latest Ordovician transgression that marked the beginning of Middle Paleozoic carbonate deposition in the east-central interior of North America probably proceeded from the south, and may have been related to deglaciation. The associated introduction of solitary coral and brachiopod assemblages that resemble those previously occurring only at continental margins foreshadowed the cosmopolitan Silurian faunas (Kaljo and Klaamann, 1973; Sheehan, 1975; Sheehan and Lespérance, 1979, p. 952). Laub (1975; 1979, pp. 45, 52) found that corals of the middle Llandovery (Lower Silurian) Brassfield Formation in the Cincinnati Arch region were geographically restricted, but show greatest similarity to those of the eastern North American continental margin.

Although assemblages in the Edgewood Province, Baltoscandia, and continental margin portions of the Red River–Stony Mountain Province are similar, they have no species in common. The solitary corals in these assemblages reflect similar normal Ordovician open marine environments, and do not necessarily indicate close genetic relationship, geographic proximity, or contemporaneity.

SYSTEMATIC PALEONTOLOGY

INTRODUCTION

Morphologic terminology and biometric methods used herein were discussed by Elias (1981, pp. 3–5). Many morphologic features are described qualitatively (for example, “slightly curved”, “moderately convex”, “closely spaced”). These terms relate specimens within the scope of this study, and their meaning is made clear by examination of the plates.

The species recognized herein are considered valid because they are separated from all others by morphologic “gaps”. Morphologic intergradation and the uncertain phylogenetic validity of Ordovician solitary streptelasmatic genera, as presently defined, are discussed for each genus. Unfortunately, knowledge of these corals is insufficient to satisfactorily resolve all difficulties at this time. Assignment of species to these genera serves to indicate particular gross morphologic features, although it is uncertain if they were determined by environment, genotype, or both. Differences in taxonomic composition among assemblages are a reflection of these factors, and the paleobiogeographic conclusions of this study are therefore thought to be valid.

Order **RUGOSA** Milne-Edwards and Haime, 1850

Family **STREPTELASMATIDAE** Nicholson in
Nicholson and Lydekker, 1889

Genus **STREPTELASMA** Hall, 1847

1847. *Streptelasma* Hall, p. 17 (as *Streptoplasma*) and page facing p. 338 (see Laub, 1979, p. 60).
1969. *Streptelasma* Hall. B. Neuman, pp. 8–10.
1974. *Streptelasma* Hall. McLean, pp. 38–41.
1979. *Streptelasma* Hall. Laub, pp. 59–61.

Type Species (by subsequent designation).—*Streptelasma corniculum* Hall (1847, p. 69); selected by Roemer (1861, p. 19). Lower Trenton Limestone (upper Middle Ordovician); Middleville, New York, U.S.A.

Discussion.—The present concept of *Streptelasma* is based on B. Neuman’s (1969, pp. 8–11) study of the type species. The genus includes streptelasmatic corals with non-dilated to moderately dilated major septa that generally are fused into a simple axial structure in early to intermediate ontogenetic stages. In later stages, the major septa are non-dilated and comparatively short, usually not forming an axial structure (see B. Neuman, 1969, fig. 3).

McLean (1974, p. 39) discussed the uncertain relationships of *Streptelasma*, *Porfiriella* Ivanovskiy (1963), and *Dinophyllum* Lindström (1882), and stated that “future study of a larger variety of material may reveal that differences between these two genera and *Streptelasma* are merely gradational, in which case they should all be considered synonymous.” B. Neuman (1977, p. 71) considered the tabellae of *Porfiriella* and *Dinophyllum* unrelated to the complete tabellae typical of *Streptelasma*. The following points must be noted in establishing the relationships of *Streptelasma*, *Borelasma* B. Neuman (1969), *Helicelasma* B. Neuman (1969), and *Grewinkia* Dybowski (1873):

1. *Streptelasma* includes corals having non-dilated and moderately dilated major septa in early stages. However, otherwise similar forms with greatly dilated septa are assigned to *Borelasma* and *Helicelasma* (see B. Neuman, 1969, figs. 22, 56). This boundary between *Streptelasma* and the latter two genera seems arbitrary.
2. The single species *S. divaricans* (Nicholson, 1875b) is highly variable and includes corals having an open axial region (as in *Streptelasma*), those in which major septa extend to the axis (also considered to be *Streptelasma*), and forms with an axial structure comparable in complexity to *Grewinkia*.

Further study may demonstrate that these genera are synonymous. A knowledge of variation within the type species *S. corniculum* is vital to this problem, but at present only the lectotype is known (B. Neuman, 1969, pp. 10, 11).

***Streptelasma divaricans* (Nicholson, 1875b)**

Plate 1, figures 1–41; Plate 2, figures 1–16;

Plate 3, figures 1–23

- 1875b. *Palaeophyllum divaricans* Nicholson, pp. 220, 221, pl. 22, fig. 10, 10a, 10b.
 1882. *Palaeophyllum divaricans* Nicholson. Hall, pp. 377, 378, pl. 52, fig. 4.
 1908. *Streptelasma divaricans* (Nicholson). Cumings, pp. 707, 708, pl. 1, fig. 6, 6a.
 1909. *Streptelasma divaricans* (Nicholson). Foerste, pp. 307, 308, pl. 10, fig. 4a–e.
 1909. *Streptelasma divaricans-angustatum* Foerste, p. 308, pl. 9, fig. 6a, 6b.
 1918. *Streptelasma* cf. *divaricans* (Nicholson). Foerste, p. 99, pl. 4, fig. 2.
 1924. *Streptelasma divaricans* (Nicholson). Foerste, p. 67, pl. 2, fig. 5a–d.

Lectotype (designated herein).—FMNH UC413; “Cincinnati Group, Cincinnati, Ohio”; U. P. James collection (Nicholson, 1875b, pl. 22, fig. 10; Pl. 3, figs. 1s, 2s).

Other Specimens.—

UCGM 45000–45143, 45611, 45646; Richmond Group; Cincinnati Arch region of Ohio, Indiana, and Kentucky (see Text-fig. 3 for stratigraphic positions and locations); Elias collection.

UCGM 45144, 45145; “Whitewater” strata of the Richmond Group; entrance to Hueston Woods Park, Oxford, Ohio; Elias collection.

USNM 311625; “Waynesville” strata (base of Clarksville beds) of the Richmond Group; near Clarksville, Ohio.

USNM 311628, 311629; “Waynesville” strata (Blanchester beds) of the Richmond Group; near Clarksville, Ohio.

USNM 135761; “Waynesville” strata (Blanchester beds) of the Richmond Group; southwest of Blanchester, Ohio.

USNM 40086; “Whitewater” strata of the Richmond Group; Oxford, Ohio.

USNM 42517; middle Richmond Group; Oxford, Ohio.

USNM 311660–311662; “Whitewater” strata of the Richmond Group; USGS locality 4343-CO, B&O railroad cut (Cincinnati, Indianapolis, and Western Railroad, NE¼, sec. 21, T5N, R1E, College Corner Quadrangle), just northwest of Oxford, Ohio; Boardman collection.

USNM 135767; “Whitewater” strata of the Richmond Group; Richmond, Indiana.

USNM 84868 (2 syntypes of *S. divaricans-angustatum*); “Whitewater” strata of the Richmond Group; Osgood, Indiana.

USNM 84869A–D (4 specimens); “Whitewater”

strata of the Richmond Group, 3.0 to 4.5 m below Brassfield Formation; Osgood, Indiana.

USNM 50816; Richmond Group; Bardstown, Kentucky.

USNM 78449 [*S. cf. divaricans* of Foerste (1918)]; Bay de Noc Member of the Stonington Formation; Stonington, Delta County, Michigan; Stratton collection.

UCGM 45146–45152; Kagawong beds, upper member of the Georgian Bay Formation; locality 19f, Manitoulin Island, Ontario (see Text-fig. 18 for stratigraphic position and location); Elias collection.

GSC 66635, 66636; Meaford beds, upper member of the Georgian Bay Formation; locality M61a, Manitoulin Island, Ontario (see Text-fig. 18 for stratigraphic position and location).

Occurrence.—Upper Ordovician (Richmondian): “Waynesville” strata to top of Richmond Group; Cincinnati Arch region of Ohio, Indiana, and Kentucky, U.S.A. Meaford and Kagawong beds, upper member of the Georgian Bay Formation; Manitoulin Island, Ontario, Canada. Bay de Noc Member of the Stonington Formation; Delta County, Michigan, U.S.A.

Diagnosis.—Coral with base of attachment, generally solitary but also occurring as pseudocolonies and rarely colonies resulting from lateral and peripheral increase. Axial region highly variable in late stage, from moderately complex axial structure of septal lobes and lamellae, to septal lobes only, to septa extending to axis, to septa withdrawn from axis—major septa most commonly extend to axis without forming axial structure.

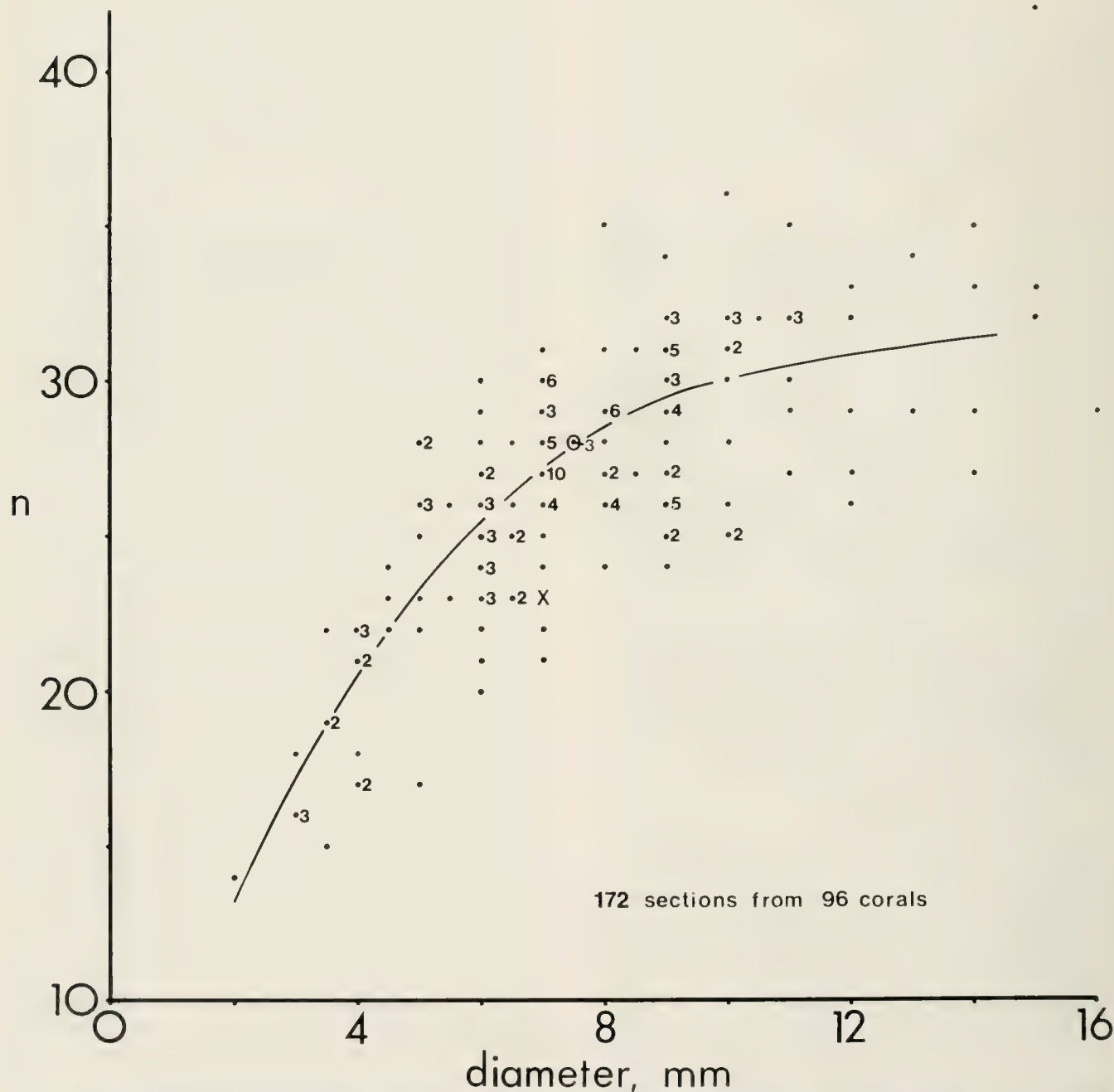
Description of Corals.—The length-frequency distribution of corals is shown in Text-figure 14 (see discussion under “Cincinnati Arch Region”). The longest specimen examined (UCGM 45013) has a length of 32 mm and diameter of 15 mm immediately below the calice where 32 major septa are present.

The corals are generally ceratoid, but some are trochoid. They rarely become cylindrical in late stages (UCGM 45025, USNM 84868). Most are slightly curved, but they vary from straight to moderately curved. The cardinal-counter surface is often slightly curved or twisted.

The corals have a relatively small to large base of attachment generally centered on the cardinal side, and less commonly toward an alar side. Some specimens have basal extensions or talons (Pl. 3, fig. 11s). This species is usually attached to bryozoans (see discussion under “Cincinnati Arch Region”). In some specimens the outer wall is absent at the site of attachment, and the septa are connected directly to the bryozoan (Pl. 3, fig. 7). Septal grooves and interseptal ridges are present on the epitheca.

Coralla generally occur individually, but 26 percent of 189 specimens consist of two or more in lateral contact (Text-fig. 13). The most seen in a single group is 13 (USNM 84869D, Foerste, 1909, pl. 10, fig. 4e). Most of these clusters apparently represent pseudo-colonies. Often the tips are separate and the coralla expand upward into lateral contact. Less commonly,

the tips are in contact or the tip of one coral is attached to the side of another, but separating walls are present. In only two specimens has lateral and peripheral increase resulting in true coloniality been demonstrated (see "Blastogeny" below). In one specimen, the walls separating two coralla opened in late stages (USNM 311660, Pl. 2, figs. 14, 15s). Two specimens show at-



Text-figure 25.—Relation between number of major septa (n) and coral diameter in *Streptelasma divaricans* (Nicholson, 1875b) from the entire Richmond Group, Cincinnati Arch region. Numbers indicate frequency of a point if greater than one. Curve determined by inspection using class averages. X = USNM 84868a [syntype of *S. divaricans-angustatum* Foerste (1909)], "Whitewater" strata, Richmond Group, Osgood, Indiana. O = USNM 78449a [*S. cf. divaricans* of Foerste (1918)], Bay de Noc Member, Stonington Formation, Stonington, Michigan.

tempted rejuvenation in later stages (UCGM 45070; USNM 311661, Pl. 2, fig. 16s).

Depth of the calice is 35 to 55 percent of the coral length. The calicular boss, when developed, is slightly convex (Pl. 2, fig. 8).

Ontogeny and Internal Structures.—In early stages the major septa commonly extend to or almost to the axis. In later stages a moderately complex axial structure of septal lobes and lamellae may develop, or a few septal lobes only may appear, or the major septa may extend to the axis, or the major septa may become withdrawn from the axis. There is a complete range of variation from corals with complex axial structures to those with open axial regions (Pl. 1, figs. 1–19; Text-fig. 16). Specimens with major septa extending to the axis are most common.

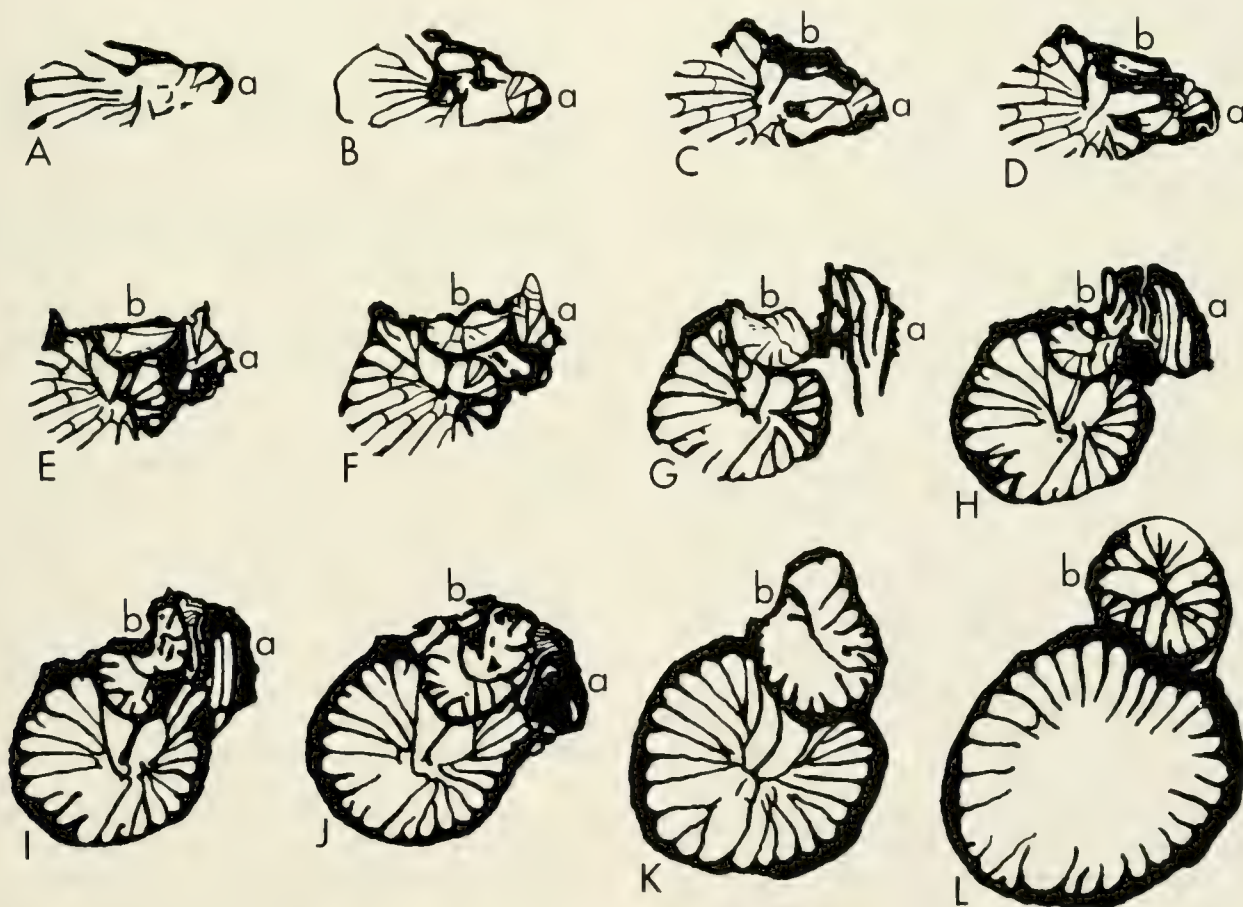
The number of major septa at a particular diameter is shown in Text-figure 25. The septa are commonly non-dilated. In a few corals the septa are slightly to moderately dilated, especially in early stages (UCGM 45018; UCGM 45128, Pl. 2, figs. 1–4). The major septa

are generally wavy and twist in a counterclockwise direction in some specimens (Pl. 1, fig. 17). They commonly meet in several groups at the axis. The cardinal septum is indistinct, and a fossula is not developed. Minor septa are confined to or extend a short distance beyond the stereozone, which is generally narrow.

Tabulae first appear in very early stages (Pl. 2, fig. 8). They are mostly complete and moderately convex upward. Complementary plates (see B. Neuman, 1969, p. 6) are present in the septal region.

Blastogeny.—In one specimen (UCGM 45646), an offset resulted from lateral increase and another arose by peripheral increase as follows (refer to Text-fig. 26):

Lateral increase. The offset (a) developed in a lateral protuberance of the elongate protocorallite. The parent septa were initially withdrawn from this region. It is not known if septa in the offset represent peripheral ends of parent septa that were left behind. A wall separating the protocorallite and offset appears as a dense region in Text-figure 26E,



Text-figure 26.—Blastogeny in *Streptelasma divaricans* (Nicholson, 1875b) [UCGM 45646, $\times 5$] (see Pl. 2, fig. 11). a = offset resulting from lateral increase. b = offset resulting from peripheral increase.

and is better defined in F. This offset was short lived, and is absent after J.

Peripheral increase. The offset (b) developed in a thickened portion of the protocorallite wall (Text-fig. 26C, D). The offset initially expanded inward at the expense of the protocorallite (E–J), as is typical of peripheral increase. Later, however, the offset curved away from the protocorallite (Pl. 2, fig. 11). The septal arrangement is irregular until L.

Increase in a second specimen (UCGM 45093) is indicated by an incomplete wall that partially separates two corallites in early stages and becomes complete in later stages (Pl. 2, figs. 12, 13). Lateral increase probably occurred in a third specimen (UCGM 45036).

Microstructure.—Septal fibers are well developed only in dilated stages (Pl. 2, fig. 9). Trabeculae are inclined slightly up toward the axis (Pl. 2, fig. 8). Lamellae in the stereozone are well developed only in non-dilated stages when the septa are relatively far apart (Pl. 2, fig. 10). The outer wall of the coral is composed of fibers oriented perpendicular to the interseptal ridges (Pl. 2, figs. 9, 10).

Discussion.—One of the two specimens figured externally by Nicholson (1875b, pl. 22, fig. 10) in the original description of *Palaeophyllum divaricans* is herein designated as the lectotype (FMNH UC413, Pl. 3, figs. 1s, 2s). His other specimen (pl. 22, fig. 10a) has not been located. The source of Nicholson's transverse section (pl. 22, fig. 10b) is unknown.

Streptelasma divaricans (Nicholson, 1875b), originally described from the Cincinnati Arch region, was assigned to *Palaeophyllum* by Nicholson (1875b) and Hall (1882), and to *Streptelasma* by later workers. Foerste (1909) distinguished *S. divaricans-angustatum* on the basis of its cylindrical form. However, its external and internal characters have been found to lie within the range of variability of *S. divaricans* (Pl. 2, fig. 5). On the basis of external morphology, a coral from Delta County, Michigan, was identified as *S. cf. divaricans* by Foerste (1918). This specimen has been sectioned and is *S. divaricans* (Pl. 3, figs. 14s, 15). The species also occurs in the upper member of the Georgian Bay Formation on Manitoulin Island.

The range of axial region variation within *S. divaricans* spans the genera *Streptelasma* and *Grewingkia* as they are presently defined. The species is assigned to *Streptelasma* because an axial structure is not developed in the majority of specimens. *S. divaricans* is distinct because it often forms pseudocolonies, and rarely forms colonies by lateral and peripheral increase. *S. (?) parasiticum* Ulrich (in Winchell and Schuchert, 1895, pp. 89, 90, fig. 6) from the "Trentonian" (upper Middle Ordovician) of Minnesota also

forms pseudocolonies or colonies attached to bryozoa, but the coralla are only several mm long—internal structures are unknown. *S. ostrogothicum* B. Neuman (1969, pp. 21–23, fig. 13b, c) from the Upper Ordovician of Sweden commonly produces several intracalicular offsets by peripheral increase, but has long minor septa and a broad stereozone. Corals of *S. divaricans* in which major septa extend to the axis resemble *S. leemonense* n. sp. from the ?Gamachian (Upper Ordovician) of Missouri. However, *S. leemonense* is distinct in having very long minor septa.

***Streptelasma leemonense* n. sp.**

Plate 4, figures 1–3

Derivation of Name.—The specific name refers to the town of Leemon, Cape Girardeau County, Missouri, near which the species occurs.

Holotype.—UCGM 45614; Elias collection (Pl. 4, figs. 1, 2).

Paratype.—UCGM 45615; Elias collection (Pl. 4, fig. 3).

Occurrence.—Upper Ordovician (?Gamachian): Leemon Formation; locality 20a, Cape Girardeau County, Missouri, U.S.A.

Diagnosis.—Solitary *Streptelasma* with major septa extending to or almost to axis during ontogeny. Minor septa very long, and may extend more than half the coral radius.

Description of Corals.—The holotype is small and has 32 major septa at a diameter of 9 mm. The paratype has 24 major septa at a diameter of 7 mm. The corals are ceratoid and slightly curved.

Ontogeny and Internal Structures.—The major septa extend to or almost to the axis, where they meet in several groups. They are non-dilated throughout ontogeny. The cardinal septum is indistinct, and a cardinal fossula is not present. The minor septa are very long, extending more than half the radius of the coral in the paratype. The stereozone is moderately broad. Tabulae are present.

Microstructure.—The microstructure of these partially silicified specimens is unknown.

Discussion.—*Streptelasma leemonense* n. sp. resembles those specimens of the Richmond Group species *S. divaricans* (Nicholson, 1875b) in which major septa extend to the axis. However, *S. leemonense* is distinct in having very long minor septa.

***Streptelasma* sp.**

Plate 4, figures 4–6

Specimen.—UCGM 45616; Elias collection.

Occurrence.—Upper Ordovician (?Gamachian): Leemon Formation; locality 20a, Cape Girardeau County, Missouri, U.S.A.

Description.—In this small solitary coral the major septa extend to or almost to the axis, where they meet in several groups throughout ontogeny. They are moderately dilated in early stages and non-dilated in later stages. The minor septa appear to be confined to the stereozone. Tabulae are present.

Microstructure.—The major septa appear to be fibrous, and lamellae are developed in the stereozone.

Discussion.—This coral resembles *Streptelasma leemonense* n. sp., from the same locality, and typical Richmond Group specimens of *S. divaricans* (Nicholson, 1875b) in that the major septa extend to or almost to the axis, where they meet in several groups. However, the degree of septal dilation is greater in this coral. The minor septa are much shorter than in *S. leemonense*. The single specimen is poorly preserved because of secondary dissolution of the periphery, and a specific name is therefore not given.

***Streptelasma subregulare* (Savage, 1913)**

Plate 4, figures 7–22

1913. *Zaphrentis subregularis* Savage, p. 62, pl. 3, fig. 5, pl. 7, fig. 1.

1913. *Zaphrentis ambigua* Savage, pp. 109, 110, pl. 7, fig. 2.

1917a. *Zaphrentis subregularis* Savage. Savage, p. 113, pl. 5, fig. 5, pl. 9, fig. 1.

1917a. *Zaphrentis ambigua* Savage. Savage, p. 149, pl. 9, fig. 2.

Holotype (by original designation).—UI X-851; Cyrene Formation, Edgewood Group; near Edgewood, Missouri; Savage collection (Savage, 1913, pl. 3, fig. 5; Savage, 1917a, pl. 5, fig. 5; Pl. 4, figs. 7s, 8).

Other Specimens.—

UI X-926 (2 specimens); Wilhelmi Formation (Channahon Limestone of Savage); Will County, Illinois; Savage collection.

UI X-947 (type specimens of *Z. ambigua*; one slab with 5 specimens plus a single specimen); Wilhelmi Formation (Channahon Limestone of Savage); near Channahon, Illinois; Savage collection.

UCGM 45618–45634; Leemon Formation; locality 20b, Cape Girardeau County, Missouri; Elias collection.

Occurrence.—Upper Ordovician (?Gamachian): Wilhelmi Formation; Will County, Illinois, U.S.A. Cyrene Formation, Edgewood Group; Pike County, Missouri, U.S.A. Leemon Formation; Cape Girardeau County, Missouri, U.S.A.

Diagnosis.—Solitary *Streptelasma* with major septa moderately dilated in early stage, non-dilated and withdrawn from axis to about half the coral radius in later stages. Cardinal septum becomes short, cardinal fossula prominent and broad in later stages.

Description of Corals.—The largest specimen ex-

amined (UCGM 45629) is 65 mm long, with a diameter of 29 mm in the calice where 37 major septa are present. The corals are trochoid (UCGM 45618, UI X-851) to usually ceratoid (UCGM 45619, UI X-947), and straight to slightly curved. Prominent septal grooves and interseptal ridges are present on the epitheca. Growth lines are preserved, and rugae are developed on some specimens. Depth of the calice is 40 (UCGM 45618) to 50 percent of the coral length (UCGM 45622). A calicular boss is not present.

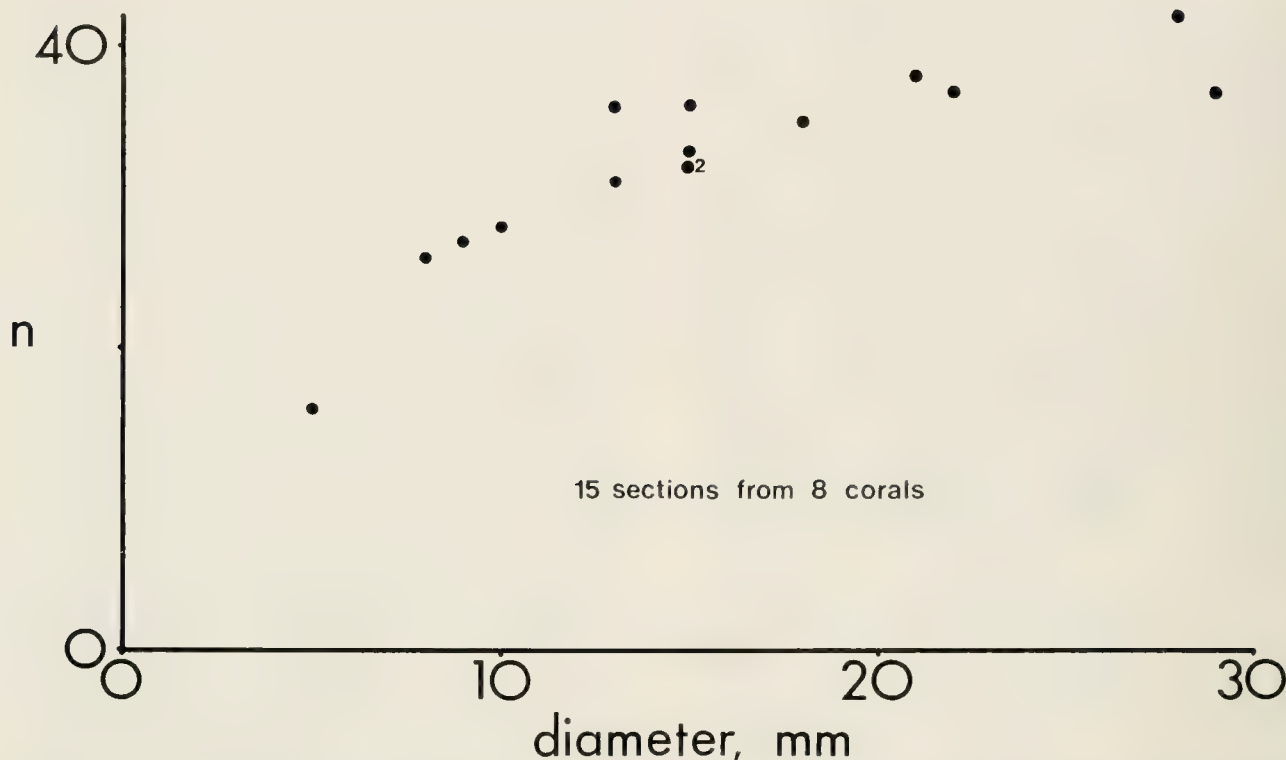
Ontogeny and Internal Structures.—In early stages the major septa extend to or almost to the axis, where they meet in several groups. In later stages they extend about half way to the axis. The septa are wavy.

The number of major septa at a particular diameter is shown in Text-figure 27. The major septa are moderately dilated in early stages and non-dilated in later stages. The cardinal septum becomes short in later stages, when a broad and prominent cardinal fossula is present. The minor septa are generally very short, and the stereozone is very narrow. The tabulae are complete, thin, very widely spaced, and somewhat irregular. They are convex upward in the septal region and horizontal to concave upward in the axial region. The tabulae are greatly depressed in the cardinal fossula (UI X-851, Pl. 4, fig. 7s).

Microstructure.—The major septa are clearly fibrous. Trabeculae are inclined up toward the axis. Lamellae appear to be present in the stereozone in non-dilated stages.

Discussion.—Savage (1913, 1917a) distinguished *Zaphrentis subregularis* and *Z. ambigua* primarily on the basis of external form, but recognized that they were similar internally. Trochoid and ceratoid specimens were assigned to *Z. subregularis* and *Z. ambigua*, respectively. In the Leemon Formation, a complete gradation from trochoid to ceratoid forms with similar internal structure is present. Therefore, *Z. ambigua* is a synonym of *Z. subregularis*, here assigned to *Streptelasma*.

Streptelasma subregulare (Savage, 1913) resembles the lectotype of *S. corniculum* Hall (1847) from the Trenton (upper Middle Ordovician) of New York (B. Neuman, 1969, pp. 10, 11, figs. 4–6) in having moderately dilated septa in early stages, major septa that are withdrawn from the axis, short minor septa, and tabulae that are concave upward in the axial region. However, *S. corniculum* does not appear to have a short cardinal septum in a prominent fossula. Many specimens of *S. affine* (Billings, 1865) from the ?Caradoc through Ashgill (Upper Ordovician) of Anticosti Island, Québec, are similar to *S. subregulare* externally and internally. The latter species is distinct in



Text-figure 27.—Relation between number of major septa (n) and coral diameter in *Streptelasma subregulare* (Savage, 1913). Numbers indicate frequency of a point if greater than one.

having a short cardinal septum in a prominent fossula, and very short minor septa.

S. subregulare most closely resembles *S. unicum* B. Neuman (1975) from the Hirnantian (Upper Ordovician) or lowermost Llandovery (Lower Silurian) of Sweden. However, *S. subregulare* has a greater degree of septal dilation in early stages, more widely spaced tabulae, and slightly fewer septa at a particular diameter (see B. Neuman, 1975, fig. 17).

***Streptelasma rankini* n. sp.**
Plate 5, figures 1–3

Derivation of Name.—The species is named for D. W. Rankin, whose field work for a doctoral dissertation at Harvard University resulted in recognition of Upper Ordovician rocks in Penobscot County, Maine.

Holotype.—USNM 311736; R. B. Neuman collection (Pl. 5, figs. 1–3).

Paratypes.—USNM 311737–311747; R. B. Neuman collection.

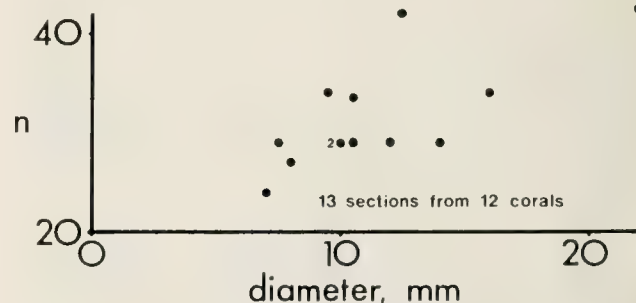
Occurrence.—Upper Ordovician (Ashgill): About 520 m above base of unnamed formation; between Pond Pitch and Haskell Rock Pitch, East Branch, Penobscot River, Penobscot County, Maine, U.S.A.

Diagnosis.—Solitary *Streptelasma* with major septa

generally slightly withdrawn from axis during ontogeny. Tabulae steeply convex upward at margins but almost horizontal or slightly concave upward axially.

Description of Corals.—The specimens are poorly preserved and incomplete. The largest coral examined (USNM 311737) has a diameter of 22 mm and 42 major septa at an unknown distance below the calice. The specimens are ceratoid. All but one (USNM 311747) appear to be straight. One individual (USNM 311738) may have a base of attachment.

Internal Structures.—The number of major septa at



Text-figure 28.—Relation between number of major septa (n) and coral diameter in *Streptelasma rankini* n. sp. Numbers indicate frequency of a point if greater than one.

a particular diameter is shown in Text-figure 28. The major septa are generally slightly withdrawn from the axis in all observed ontogenetic stages. They are non-dilated and wavy. The cardinal septum is indistinct, and a fossula is not developed. Minor septa commonly extend a moderate distance beyond the stereozone, but may be very long (USNM 311739). The stereozone is moderately broad. The tabulae are thin and mostly complete. They are steeply convex upward at the margins, but become almost horizontal or are slightly concave upward axially. Complementary plates (see B. Neuman, 1969, p. 6) are present in some specimens.

Microstructure.—The corals are poorly preserved. Septal fibers cannot be distinguished, but weakly developed trabeculae that are slightly inclined up toward the axis may be present.

Discussion.—*Streptelasma rankini* n. sp. resembles some specimens of *S. affine* (Billings, 1865) from the ?Caradoc through Ashgill (Upper Ordovician) of Anticosti Island, Québec, and *S. primum* (Wedekind, 1927) from the Ashgill of Norway in growth form and in having major septa withdrawn from the axis. However, *S. rankini* has tabulae that are much more steeply convex upward at the margins.

***Streptelasma affine* (Billings, 1865)**

Plate 5, figures 4–18

1865. *Zaphrentis affinis* Billings, p. 430.

1865. *Zaphrentis bellistriata* Billings, pp. 430, 431.

1866. *Zaphrentis affinis* Billings. Billings, p. 7.

1866. *Zaphrentis bellistriata* Billings. Billings, p. 8.

1901. *Zaphrentis affinis* Billings. Lambe, pp. 118, 119, pl. 7, fig. 6, 6a, 6b.

1928. *Zaphrentis affinis* Billings. Twenhofel, pp. 114, 115.

1981. *Streptelasma affinis* (Billings). Bolton, pl. 3, figs. 3–8.

Lectotype (designated herein).—GSC 1987, 1987c–e; upper member, about 30+ m below top of Vauréal Formation; Wreck Point, Anticosti Island, Québec; T. C. Weston collection, 1865.

Paralectotypes (designated herein).—GSC 1987a, b (Lambe, 1901, pl. 7, fig. 6, 6a); GSC 1987g, i; GSC 1987f, h; upper member, about 30+ m below top of Vauréal Formation; Wreck Point, Anticosti Island, Québec; T. C. Weston collection, 1865.

Other Specimens.—

(All from Anticosti Island, Québec; Twenhofel collection unless otherwise stated.)

GSC 2244, 2244a, b (syntype of *Zaphrentis bellistriata*); upper member, about 30+ m below top of Vauréal Formation; Wreck Point; T. C. Weston collection, 1865.

YPM 28687; lower member of the Vauréal Formation (Twenhofel's zone 4, English Head Formation); Carleton Point.

YPM 28688; Ellis Bay Formation; cliff 1.2 km east of Junction Cliff.

YPM 28689, 28693; Ellis Bay Formation; Prinsta Bay.

YPM 28690; Ellis Bay Formation; near Junction Cliff.

YPM 28691; Ellis Bay Formation; west side of Prinsta Bay.

YPM 28692; Ellis Bay Formation; west side of Ellis Bay.

YPM 28685, 28686; upper Ellis Bay Formation; reef at little cliff between Bear Cape and Cape Eagle.

YPM 28694; Twenhofel's zone 1, Ellis Bay Formation; west side of Ellis Bay.

YPM 28695–28699; Twenhofel's zone 1, Ellis Bay Formation; Junction Cliff.

YPM 28700; Twenhofel's zone 2, Ellis Bay Formation; coral and *Beatricea* zones, Lousey Cove.

YPM 28701–28704; Twenhofel's zone 2, Ellis Bay Formation; Junction Cliff.

YPM 28705, 28706; Twenhofel's zone 5, Ellis Bay Formation; Ellis Bay.

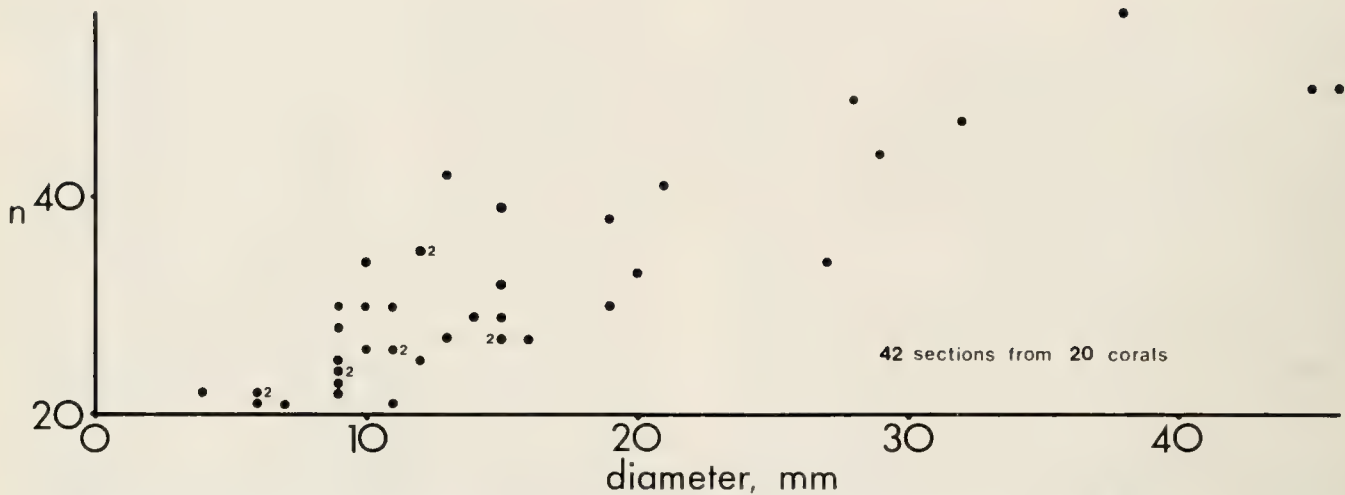
YPM 28707; Twenhofel's zone 7 (*Hormotoma gigantea* zone), Ellis Bay Formation; Ellis Bay.

YPM 28708, 28709; Twenhofel's zone 9, Ellis Bay Formation; Ellis Bay.

Occurrence.—Upper Ordovician: Lower member (?Caradoc) and upper member (lower to middle Ashgill) of the Vauréal Formation, and Ellis Bay Formation (Ashgill; Gamachian); Anticosti Island, Québec, Canada.

Diagnosis.—Solitary *Streptelasma* with major septa generally withdrawn from axis in intermediate and late stages, sometimes extending less than half the coral radius. Cardinal fossula not developed. Minor septa generally long, extending well beyond stereozone.

Description of Corals.—The largest specimen examined (GSC 1987g, i) is a fragment 120 mm long, with a maximum diameter of 55 mm and a diameter of 37 mm at the incomplete base. The greatest number of major septa observed is 70 at a diameter of 43 mm (YPM 28706). The corals are ceratoid to trochoid and slightly to moderately curved in early stages, and become cylindrical and generally straight in later stages. Prominent septal grooves and interseptal ridges are present on the epitheca. Coarse rugae are often developed, and some are regularly spaced at intervals of 8 to 13 mm. Talons are present in early stages of some specimens (Pl. 5, fig. 9). Depth of the calice is 30 (YPM 28706) to 60 percent of the coral length (GSC 1987, 1987c–e). The base of the calice is generally concave upward (Pl. 5, fig. 10).



Text-figure 29.—Relation between number of major septa (n) and coral diameter in *Streptelasma affine* (Billings, 1865). Numbers indicate frequency of a point if greater than one.

Ontogeny and Internal Structures.—In early stages the major septa extend to or almost to the axis. In intermediate and late stages they may extend almost to the axis where a few septal lobes are present in some specimens (YPM 28709, Pl. 5, figs. 16–18), but are generally withdrawn (Pl. 5, figs. 12, 13) and may extend less than half way to the axis (YPM 28698). The septa are commonly wavy.

The number of major septa at a particular diameter is shown in Text-figure 29. The major septa are usually moderately dilated in early stages, but are non-dilated in some specimens. They are non-dilated in later stages. In small corals, the major septa rarely twist in a counterclockwise direction when viewed from the calice (YPM 28687, 28703, 28707). The cardinal septum is indistinct, and a fossula is not developed. The minor septa commonly are long and extend well beyond the stereozone. The stereozone is generally narrow, but ranges from very narrow (YPM 28687, 28694) to broad (YPM 28705).

A few thin tabellae inclined up toward the axis are present in the septal region. Complete and incomplete tabulae are developed. Within a single coral, they may vary from thin to moderately thick, and may be very closely to widely spaced. They are convex upward in the septal region and concave upward in the axial region (Pl. 5, fig. 10).

Microstructure.—Septal fibers are distinguishable only in dilated stages. The weakly developed trabeculae are inclined slightly up toward the axis. In non-dilated stages, lamellae are developed in the stereozone.

Discussion.—One specimen (GSC 1987, 1987c–e) is selected from Billings' syntypes as the lectotype of *Streptelasma affine* (Billings, 1865) because it has

been sectioned transversely. One of the paralectotypes designated herein (GSC 1987a) was figured by Lambe (1901, pl. 7, fig. 6, 6a), but has not been sectioned transversely. The source of the transverse section in Lambe's plate 7, figure 6b is unknown.

A transverse and longitudinal section of a syntype of *Zaphrentis bellistriata* Billings (1865) (GSC 2244, 2244a, b) indicate that it is a synonym of *S. affine*, as noted by Lambe (1901) and Twenhofel (1928).

Specimens of *S. affine* having ceratoid form and septa only slightly withdrawn from the axis resemble *S. rankini* n. sp. from the Ashgill (Upper Ordovician) of Maine. However, *S. rankini* has tabulae that are much more steeply convex upward at the margins. *S. affine* is often similar externally and internally to *S. subregulare* (Savage, 1913) from the ?Gamachian (Upper Ordovician) of Illinois and Missouri, but has a longer cardinal septum and longer minor septa, and lacks a prominent cardinal fossula. *S. affine* most closely resembles *S. primum* (Wedekind, 1927) (see B. Neuman, 1969, pp. 11–17) from the Ashgill (Upper Ordovician) of Norway in growth form and in having short major septa and tabulae that are concave upward axially. However, the long minor septa and deep calice of *S. affine* are distinct. *S. sp. cf. S. primum* from the Upper Ordovician Centrum Formation of northeastern Greenland has more septa at a particular diameter and shorter minor septa than *S. affine* (see Scrutton, 1975, pp. 15, 16, pl. 2, fig. 1).

Genus *HELICELASMA* B. Neuman, 1969

1969. *Helicelasma* B. Neuman, pp. 28, 29.

1981. *Helicelasma* B. Neuman. Elias, pp. 19, 20.

Type Species (by original designation).—*Helicelasma simplex* B. Neuman (1969, pp. 29–33). *Dalmani-*

tina beds (Upper Ordovician); Borenshult, Östergötland, Sweden.

Discussion.—*Helicelasma* was proposed by B. Neuman (1969) to include solitary corals having greatly to completely dilated major septa extending to the axis in early and intermediate ontogenetic stages. In later stages the degree of dilation is not as great and the major septa generally join into a loosely built axial structure (see B. Neuman, 1969, fig. 22). The diagnosis was based primarily on the type species.

The uncertain relationship between *Helicelasma* and *Streptelasma* Hall (1847) was discussed under the latter genus. The following points suggest that *Helicelasma*, *Grewingkia* Dybowski (1873), *Leolasma* Kaljo (1956), and *Borelasma* B. Neuman (1969) may be synonymous:

1. An axial region is not present in some specimens of *H. randi* Elias (1981), but in others it is as large as that of *Grewingkia* and a simple axial structure is developed.
2. Species of *Helicelasma* such as *H. selectum* (Billings, 1865), in which tabulae are rare and major septa are sometimes fused axially into a solid structure, approach *Leolasma* (see B. Neuman, 1975, fig. 2).
3. *Helicelasma* includes corals having a simple axial structure and those in which major septa extend to or almost to the axis in late ontogenetic stages. Forms that have an open axial region in late stages but are otherwise similar are assigned to *Borelasma* (see B. Neuman, 1969, fig. 56). However, *Streptelasma* includes corals having a simple axial structure and those in which septa extend to or almost to the axis, as well as forms having an open axial region in late stages (see B. Neuman, 1969, fig. 3). The boundary between *Helicelasma* and *Borelasma* therefore seems arbitrary.

***Helicelasma randi* Elias, 1981**

Plate 6, figures 1–9

1981. *Helicelasma randi* Elias, pp. 20, 21, pl. 8, figs. 1–18, pl. 9, figs. 1–11.

Holotype.—GSC 60735; Selkirk Member of the Red River Formation; Garson, Manitoba; Rand collection (Elias, 1981, pl. 8, figs. 1–8).

Paratypes (all from Selkirk Member of the Red River Formation; Garson, Manitoba).—GSC 60730 (Elias, 1981, pl. 9, figs. 3–11), 60731, 60732, 60733 (Elias, 1981, pl. 9, figs. 1, 2). GSC 60729 (Elias, 1981, pl. 8, figs. 9–18), 60734; Rand collection. GSC 60736–60739; Elias collection.

***Specimens Described Herein.*—**

SUI 57-'24; probably Clermont Member, Scales Formation, Maquoketa Group; SW¼, sec. 21 or NW¼, sec. 28, Clermont Township, Fayette County, Iowa.

USNM 311630–311632; Brainard Formation, Maquoketa Group; Sterling, Illinois.

USNM 311641–311643; Brainard Formation, Ma-

quoketa Group; Sterling, Illinois; Ulrich and Bassler collection.

USNM 311644–311646; Brainard Formation, Maquoketa Group; Sterling, Illinois; Ulrich and Bassler collection.

USNM 311633, 311634; Brainard Formation, Maquoketa Group; SE¼, SE¼, sec. 35, T91N, R6W, Clayton County, Iowa; Gerk collection.

SIU 4200, 4201; Orchard Creek Member of the Scales Formation, Maquoketa Group; bank of Mississippi River, 1.6 km north of Thebes, SE¼, sec. 5, T15S, R3W, Alexander County, Illinois; Guensburg collection.

Occurrence.—Upper Middle (?) and Upper Ordovician: Selkirk Member of the Red River Formation (upper Middle or Upper Ordovician); Garson, Manitoba, Canada. Probably Clermont Member, Scales Formation (Richmondian), Maquoketa Group; Fayette County, Iowa, U.S.A. Orchard Creek Member of the Scales Formation (Richmondian), Maquoketa Group; Alexander County, Illinois, U.S.A. Brainard Formation (Richmondian), Maquoketa Group; Clayton County, Iowa, and Sterling, Illinois, U.S.A.

Diagnosis.—*Helicelasma* usually with simple axial structure of a few septal lobes and lamellae in later stages. Dilation of major septa slight to complete in early stage, commonly producing a solid axis or a ring around axial region. Septa non-dilated in late stage. Cardinal septum generally long and thin, cardinal fossula moderately broad. Tabulae convex upward if developed.

Description of Corals.—The largest specimen examined (USNM 311641) has a length of 63 mm and diameter of 23 mm immediately below the calice where 40 major septa are present. The corals are trochoid, and straight to slightly curved. Septal grooves and interseptal ridges are present on the epitheca. Depth of the calice is 30 percent of the coral length (USNM 311644). The calicular boss is highly convex (USNM 311644, Pl. 6, fig. 7).

Ontogeny and Internal Structures.—In early stages the major septa extend to or almost to the axis. In intermediate and late stages a few septal lobes and lamellae develop in the axial region. Groups of two or more major septa commonly converge near the axis. The number of major septa at a particular diameter is shown in Text-figure 30. In early stages, septal dilation is complete (USNM 311641) to moderate (USNM 311630). Dilation near the axis produces a ring around the axial region in some specimens (USNM 311630, Pl. 6, figs. 3, 4; SIU 4200). The cardinal septum is long and thinner than the other major septa. The cardinal fossula is moderately broad. Minor septa are confined

to or extend a short distance beyond the moderately broad stereozone. In later stages the tabulae are complete, relatively widely spaced, and moderately convex upward (Pl. 6, fig. 7).

Microstructure.—The microstructure is unknown because of poor preservation.

Discussion.—These specimens from the Maquoketa Group of Iowa and Illinois cannot be distinguished morphologically from *Helicelasma randi* Elias (1981) of the Selkirk Member, Red River Formation, in southern Manitoba. The number of major septa at a particular diameter is similar in both units, although corals from the Maquoketa tend to have slightly lower values (Text-fig. 30). The specimen from Clermont Township, Iowa, probably from the Clermont Member of the Scales Formation (Pl. 6, fig. 8), has a larger axial region than those from the Brainard Formation (Pl. 6, figs. 4, 6).

The relationship of *H. randi* with other species of the genus was discussed by Elias (1981, p. 21). *H. selectum* (Billings, 1865) from the Ashgill (Upper Ordovician) of Québec is similar in the latest ontogenetic stages, when a small axial structure consisting of a few dilated septal lobes and lamellae is present, and the

thin cardinal septum is located in a moderately broad fossula. However, *H. selectum* differs in having completely dilated septa except in late stages immediately below the calice where the cardinal septum commonly is short, and in generally possessing fewer septa than *H. randi* at a particular coral diameter (Text-figs. 30, 31).

***Helicelasma selectum* (Billings, 1865)**

Plate 6, figures 10–20

1865. *Petraia selecta* Billings, p. 429 [partim].

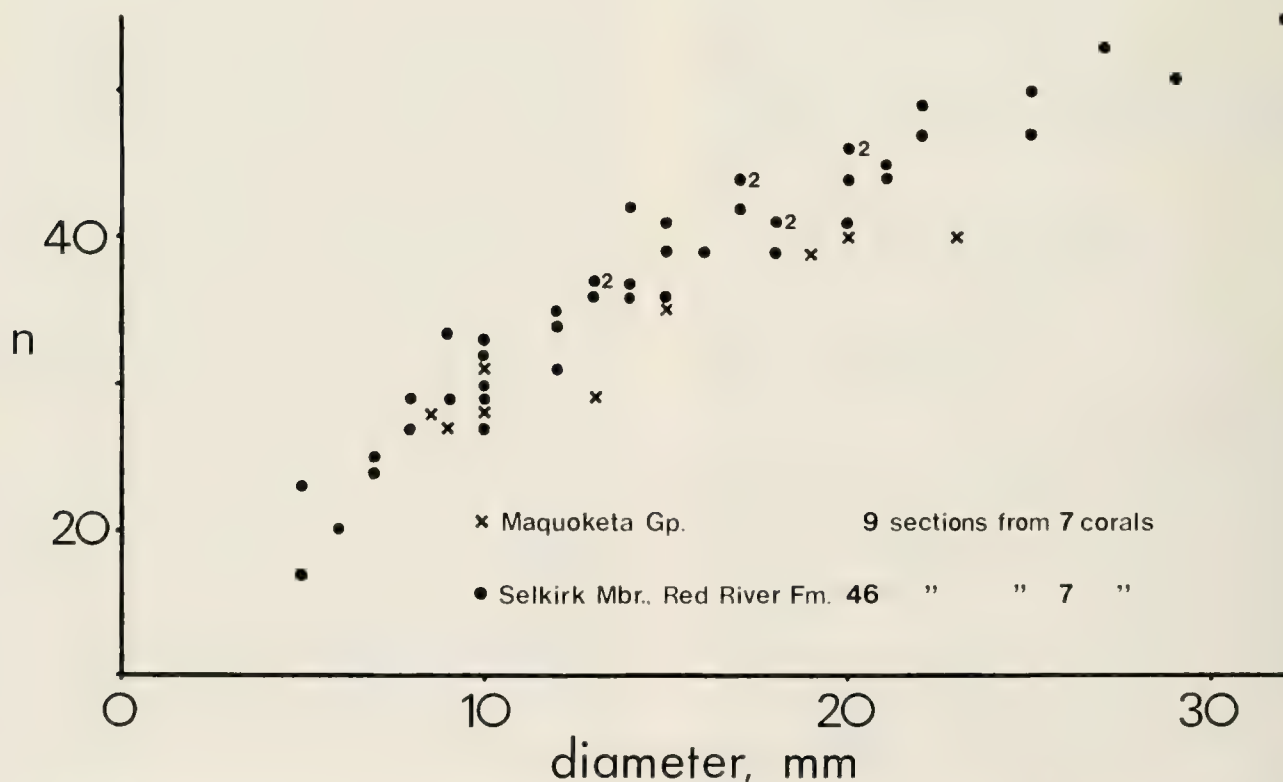
1866. *Petraia selecta* Billings, Billings, p. 7 [partim].

1901. *Streptelasma selectum* (Billings). Lambe, p. 113 [partim], non pl. 6, fig. 8, 8a.

1928. *Streptelasma selectum* (Billings). Twenhofel, p. 113 [partim].

Lectotype (designated herein).—GSC 1989a, b; upper member, about 27 to 30 m below top of Vauréal Formation; west end lighthouse, Anticosti Island, Québec; J. Richardson collection, 1856 (Pl. 6, figs. 10, 11).

Paralectotypes (designated herein).—GSC 1989, 1989g; GSC 1989c, d; GSC 1989f; upper member, about 27 to 30 m below top of Vauréal Formation; west end lighthouse, Anticosti Island, Québec; J.



Text-figure 30.—Relation between number of major septa (n) and coral diameter in *Helicelasma randi* Elias (1981) from the Selkirk Member, Red River Formation, southern Manitoba (see Elias, 1981, fig. 13b) and the Maquoketa Group. Numbers indicate frequency of a point if greater than one.

Richardson collection, 1856.

Other Specimens.—

(All from Twenhofel collection, Anticosti Island, Québec, unless otherwise stated.)

YPM 28710; upper member (English Head facies) of the Vauréal Formation; English Head.

YPM 28711; upper member (English Head facies) of the Vauréal Formation; West Bay.

YPM 28712; Ellis Bay Formation; Cape James.

YPM 28713; Ellis Bay Formation; zone 21 of Twenhofel's Vauréal River section.

YPM 28714; basal unit, Ellis Bay Formation; zone 10 of Twenhofel's Vauréal River section.

YPM 28715; Twenhofel's zone 2, Ellis Bay Formation; coral and *Beatricea* zones, Lousey Cove.

USNM 311636, 311637, and YPM 28716; *Stenoporeia* faunal zone, White Head Formation; Grande Coupe, 2.4 km northwest of Percé, Québec.

Occurrence.—Upper Ordovician: Upper member (lower to middle Ashgill) of the Vauréal Formation, and Ellis Bay Formation (Ashgill; Gamachian); Anticosti Island, Québec, Canada. White Head Formation (lower to middle Ashgill); Percé, Québec, Canada.

Diagnosis.—*Helicelasma* with small axial structure of a few dilated septal lobes and lamellae in late stage. Septa generally completely dilated until immediately below calice in late stage, where dilation is slight to great. Cardinal septum thin and commonly short in late stage, cardinal fossula moderately broad. Tabulae rare.

Description of Corals.—The longest specimen observed (YPM 28712) is incomplete, and has a length of 50 mm. The broadest specimen (YPM 28715) has a diameter of 27 mm. The maximum number of septa observed is 44 at a diameter of 25 mm (USNM 311637). The corals are trochoid and slightly curved. Weakly developed septal grooves and interseptal ridges are preserved on the epitheca of some specimens (GSC 1989, 1989g). Depth of the calice is 40 percent of the coral length (GSC 1989a, b; GSC 1989c, d). A calicular boss is not developed.

Ontogeny and Internal Structures.—In early stages the major septa extend to the axis. In intermediate stages, a few completely dilated septal lobes are present at the axis, and in late stages a few dilated septal lamellae may develop in the small axial structure. The number of major septa at a particular diameter is shown in Text-figure 31. The septa are generally completely dilated except in late stages immediately below the calice, where septa are slightly (USNM 311637) to more commonly greatly dilated. In late stages the cardinal septum is thin and generally very short. The cardinal fossula is moderately broad. The minor septa are

moderately long, and some extend a short distance beyond the moderately broad stereozone in slightly dilated late stages. A few tabulae are present in some specimens (GSC 1989a, b).

Microstructure.—Septal fibers are well developed and the trabeculae are slightly inclined up toward the axis. Lamellae commonly are present in the stereozone.

Discussion.—Specimens collected in 1856 by Richardson at the west end lighthouse on Anticosti Island (GSC 1989, 1989a–n) were probably used by Billings in his original description of *Petraia selecta*. They are considered to be syntypes. However, two species are represented in this collection. One is *Grewingkia pulchella* (Billings, 1865). The other is considered to be *Helicelasma selectum* (Billings, 1865), for which a lectotype and paralectotypes are herein selected. Billings' *Petraia pulchella* was considered a synonym of *P. selecta* by Lambe (1901) and Twenhofel (1928), but two species are definitely involved.

In the latest ontogenetic stages, *H. selectum* resembles *H. randi* Elias (1981) from the upper Middle or Upper Ordovician of southern Manitoba and Richmondian (Upper Ordovician) of Iowa and Illinois. Both species have a small axial structure of a few dilated septal lobes and lamellae, and the thin cardinal septum is located in a moderately broad fossula. However, *H. selectum* is distinct in having completely dilated septa except in late stages immediately below the calice where the cardinal septum is usually short, and in commonly possessing fewer septa than *H. randi* at a particular diameter (Text-figs. 30, 31).

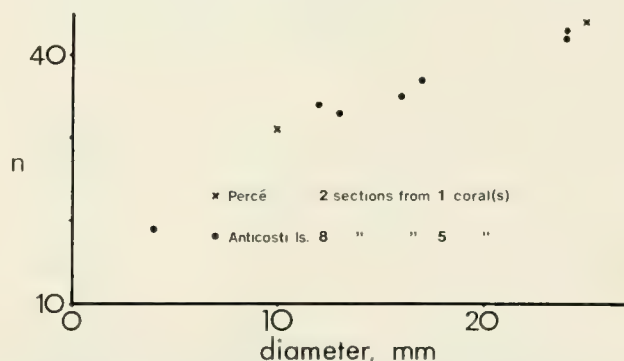
Genus *DEIRACORALLIUM* Nelson, 1963

1963. *Deiracorallium* Nelson, p. 37.

1981. *Deiracorallium* Nelson. Nelson, pp. 52, 53.

1981. *Deiracorallium* Nelson. Elias, pp. 21, 22.

Type species (by original designation).—*Deiracorallium manitobense* Nelson (1963, pp. 37, 38). Church-



Text-figure 31.—Relation between number of major septa (n) and coral diameter in *Helicelasma selectum* (Billings, 1865).

ill River Group (Upper Ordovician); Hudson Bay Lowland, northern Manitoba, Canada.

Discussion.—*Deiracorallium* was proposed by Nelson (1963) to include compressed solitary corals having a markedly angulate convex cardinal side and greatly dilated major septa that extend to the axis without twisting. This diagnosis was based on the small type species *D. manitobense* Nelson (1963). It may be conspecific with *D. angulatum* (Billings, 1862) of Anticosti Island, Québec, a possibility recognized by Nelson (1963, p. 38; 1981, p. 54) and discussed under the species herein. *D. giganteum* Nelson (1963) is of moderate size and has major septa that twist in the axial region. *D. harveyi* Nelson (1981) and *D. delicatum* Elias (1981) attain moderately large size and in later ontogenetic stages have slightly dilated major septa and a small axial structure of septal lobes and lamellae. Therefore, the genus was expanded by Nelson (1981) and Elias (1981) to include compressed forms with a small axial structure.

The following points suggest that *Deiracorallium*, *Grewingkia* Dybowski (1873), and *Leolasma* Kaljo (1956) are closely related and possibly synonymous:

1. Large species of *Deiracorallium* such as *D. delicatum* and *D. harveyi* differ from *Grewingkia* in that the corals are compressed and the axial structure is smaller. However, *G. robusta* (Whiteaves, 1896) and *G. haysii* (Meek, 1865) are sometimes compressed, and both *D. delicatum* and *G. robusta* can be triangulate to slightly trilobate (see Elias, 1981). The significance of external form as a diagnostic generic trait is therefore questionable. Variability in complexity and size of the axial structure in *Grewingkia* is great, as will be discussed under that genus.
2. Except for external form, small species such as *D. angulatum* resemble *Leolasma*, which is circular in cross-section (see B. Neuman, 1975, fig. 2). The major septa are greatly to completely dilated until immediately below the calice where dilation decreases except around the axis, and tabulae are rare or absent.

***Deiracorallium angulatum* (Billings, 1862)**

Plate 6, figures 21–33

1862. *Petraia angulata* Billings, p. 103, fig. 90a, 90b.
 1901. *Streptelasma angulatum* (Billings). Lambe, p. 112.
 1928. *Streptelasma angulatum* (Billings). Twenhofel, pp. 111, 112, pl. 3, fig. 5.
 1937. "*Streptelasma angulatum* (Billings)". Cox, p. 4, pl. 1, fig. 5.
 1943. [?] *Streptelasma trilobatum* (Whiteaves). Okulitch, pl. 1, figs. 13, 14.
 1959b. [?] "*Streptelasma angulatum* (Billings)". Nelson, pl. 4, fig. 2a, 2b.
 1963. [?] *Deiracorallium manitobense* Nelson, pp. 37, 38, pl. 13, figs. 1, 2a, 2b.
 1963. [?] *Deiracorallium manitobense* var. *churchillense* Nelson, p. 38, pl. 13, fig. 3a, 3b.
 1981. [?] *Deiracorallium manitobense* Nelson. Nelson, pp. 53, 54, pl. 8, figs. 13, 14.
 1981. [?] *Deiracorallium manitobense churchillense* Nelson. Nelson, p. 54, pl. 8, fig. 12.

Lectotype (listed as holotype by Twenhofel, 1928).—GSC 1984, 1984a; upper member, about 30+ m below top of Vauréal Formation; west end camp, Anticosti Island, Québec; J. Richardson collection, 1856 (Twenhofel, 1928, pl. 3, fig. 5; Cox, 1937, pl. 1, fig. 5).

***Other Specimens.*—**

(All from Anticosti Island, Québec.)

GSC 66592–66619; upper member, 60+ m below top of Vauréal Formation; GSC locality 84419, main highway section on upper elevation east of Potatoe River crossing; Bolton collection.

YPM 28717–28720; Twenhofel's zone 5, upper member of the Vauréal Formation; Twenhofel collection.

Occurrence.—Upper Ordovician (lower to middle Ashgill); Upper member of the Vauréal Formation; Anticosti Island, Québec, Canada.

Diagnosis.—*Deiracorallium* with major septa extending to axis throughout ontogeny. Septal dilation great to complete until immediately below calice, where it decreases except around axis. Cardinal septum short and thin in latest stage. Tabulae rare.

Description of Corals.—The largest specimen examined has a length of 23 mm. The maximum number of major septa observed is 36 at a height of 9 mm (GSC 66593). The corals are ceratoid to trochoid. They are slightly to moderately curved, greatly compressed, and triangulate in early stages. Later, curvature decreases, coral expansion decreases or ceases, and compression and triangulation decrease. Weakly developed septal grooves and interseptal ridges are present on the epitheca. Depth of the calice is 30 percent of the coral length. A calicular boss is not developed.

Ontogeny and Internal Structures.—The major septa extend to or almost to the axis throughout ontogeny. The number of major septa at a particular height is shown in Text-figure 32. As would be expected, trochoid corals have more septa at a particular height than do ceratoid forms. The septa are greatly to completely dilated until immediately below the calice, where dilation decreases except around the axis. The cardinal septum is short and thin in late stages, and the cardinal fossula is narrow. In late stages immediately below the calice, the length of minor septa varies from those confined to the moderately broad stereozone (GSC 66592, Pl. 6, fig. 24) to those extending well beyond it (GSC 66593, Pl. 6, fig. 31). Tabulae are rare in late stages.

Microstructure.—Septal fibers are well developed, and the trabeculae are slightly inclined up toward the axis. Lamellae are not present in the stereozone.

Discussion.—Billings' (1862) original description of *Petraia angulata* was based on three syntypes, one of

which was figured. Twenhofel (1928) listed and figured one specimen as the holotype (GSC 1984), and listed a paratype (GSC 1984a). However, the latter is a thin section of the former. Cox (1937) listed and figured this thin section as the holotype, but it is not the original of Billings' figure, as he stated. Only one syntype of this species is known (GSC 1984, 1984a). It is the lectotype of *Deiracorallium angulatum* (Billings, 1862).

Specimens of *Deiracorallium* in the Upper Ordovician Stony Mountain Formation of southern Manitoba were assigned to *Streptelasma trilobatum* by Okulitch (1943), to "*S. angulatum*" by Nelson (1959b), and to *D. manitobense* by Nelson (1963, 1981). Similar specimens from the correlative Caution Creek and Chasm Creek Formations of northern Manitoba were assigned to *D. manitobense* and *D. manitobense churchillense* by Nelson (1963, 1981). These corals from Manitoba may be conspecific with *D. angulatum*, a possibility recognized by Nelson (1963, p. 38; 1981, p. 54). All have similar numbers of septa at a particular height (Text-fig. 32). Definite assignment must await further sectioning and study of the forms from Manitoba.

Genus GREWINGKIA Dybowski, 1873

1873. *Grewingia* Dybowski, p. 384.

1969. *Grewingia* Dybowski. B. Neuman, pp. 33–36.

1974. *Grewingia* Dybowski. McLean, pp. 42–44.

1981. *Grewingia* Dybowski. Nelson, p. 41.

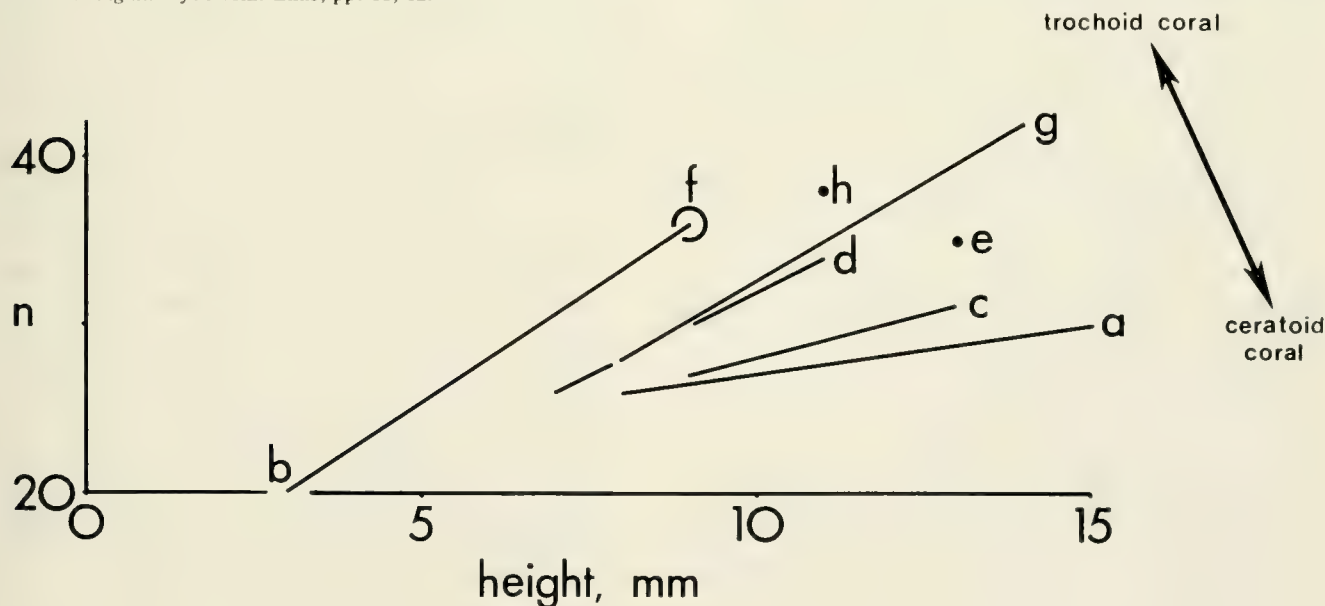
1981. *Grewingia* Dybowski. Elias, pp. 11, 12.

Type Species (by subsequent designation).—*Clisio-phyllum buceros* Eichwald (1856, p. 108); selected by Sherzer (1891, p. 284; see Kaljo, 1961, p. 53). Type stratum and locality unknown (see Kaljo, 1961, p. 54).

Discussion.—Until B. Neuman's (1969) examination of variability within *Grewingia*, diagnoses of the genus were based almost entirely on characteristics of the type species alone. The degree of septal dilation and nature of the axial structure are the most variable morphologic features (see B. Neuman, 1969, fig. 27). As presently understood, the genus includes species such as *G. penobscotensis* n. sp. and *G. anguinea* (Scheffen, 1933) that have slightly dilated major septa in early ontogenetic stages, and *G. rustica* (Billings, 1858a) in which dilation is complete in early stages and great even in later stages. In general, the axial structure of *Grewingia* is relatively large and consists of numerous septal lobes and lamellae in later stages.

The uncertain relationships of *Grewingia*, *Streptelasma* Hall (1847), *Helicelasma* B. Neuman (1969), and *Deiracorallium* Nelson (1963) were discussed under the latter three genera. The following points suggest that the sequence *Borelasma* B. Neuman (1969) → *Helicelasma* → *Grewingia* → *Lobocorallium* Nelson (1963) is gradational:

1. The single species *G. canadensis* (Billings, 1862) is highly variable and includes corals having an open axial region as in *Borelasma* (see B. Neuman, 1969, fig. 56), those resembling *Helicelasma*



Text-figure 32.—Relation between number of major septa (n) and coral height, and coral form in species of *Deiracorallium*.

a–d. GSC 66592–66595, *D. angulatum* (Billings, 1862), upper member, Vauréal Formation, Anticosti Island, Québec.

e. GSC 10846, paratype of *D. manitobense* Nelson (1963), member No. 1, Caution Creek Formation, northern Manitoba.

f. GSC 10847, holotype of *D. manitobense churchillense* Nelson (1963), member No. 1, Chasm Creek Formation, northern Manitoba.

g, h. GSC 66620, 66621, *Deiracorallium* sp., Gunn Member, Stony Mountain Formation, Stony Mountain, Manitoba.

celasma in having major septa that extend to the axis (see B. Neuman, 1969, fig. 22), and forms with simple to complex axial structures in late ontogenetic stages, as is characteristic of *Grewingkia*.

2. The following continuous morphologic sequence between *Grewingkia* and *Lobocorallium* is recognized, and involves an increase in the degree of trilobation and septal dilation, and a decrease in the number of tabulae: *G. robusta* (Whiteaves, 1896) → *G. haysii* (Meek, 1865) → *L. trilobatum vaurealense* (Twenhofel, 1928) → *L. trilobatum trilobatum* (Whiteaves, 1895) [see Elias (1981), and *Lobocorallium* herein].

***Grewingkia canadensis* (Billings, 1862)**

Plate 7, figures 1–21; Plate 8, figures 1–30;

Plate 9, figures 1–21; Plate 10, figures 1–28

1851. *Streptelasma corniculum* Hall. Milne-Edwards and Haime, pp. 398, 399 [partim], pl. 7, fig. 4, 4a, 4b.
1862. *Zaphrentis canadensis* Billings, pp. 105, 106, fig. 93a–c.
1863. *Petraia canadensis* (Billings). Geological Survey of Canada, fig. 205.
- 1875a. *Streptelasma corniculum* Hall. Nicholson, pp. 26, 27 [partim].
- 1875b. *Streptelasma corniculum* Hall. Nicholson, pp. 218, 219 [partim].
1876. *Streptelasma corniculum* Hall. Nicholson, p. 94, pl. 5, fig. 15, 15a.
1876. *Streptelasma corniculum* Hall. Rominger, pp. 142, 143 [partim], pl. 51, upper tier [partim].
1882. *Streptelasma corniculum* Hall. Hall, p. 376 [partim], pl. 51, figs. 2–4.
1901. *Streptelasma rusticum* (Billings). Lambe, pp. 110–112 [partim], non pl. 7, figs. 2, 2a, 3.
1908. *Streptelasma rusticum* (Billings). Cumings, pp. 708, 709 [partim], pl. 2, fig. 2, 2a, 2b.
1909. *Streptelasma vagans* Foerste, pp. 305, 306, pl. 11, fig. 1a–c.
1909. *Streptelasma insolitum* Foerste, p. 306, pl. 10, fig. 3.
1909. *Streptelasma disbandum* Foerste, p. 307, pl. 9, fig. 4a, 4b.
1924. *Streptelasma rusticum* (Billings). Foerste, pp. 65, 66 [partim], pl. 1, figs. 1a–c, 2a–c, pl. 2, fig. 6a–c.
1924. *Streptelasma disbandum* Foerste. Foerste, pp. 66, 67, pl. 2, fig. 4.
1932. *Streptelasma rusticum* (Billings). Bassler, pl. 24, figs. 16, 17.
1937. *Streptelasma rusticum* (Billings). Cox, pp. 11–13 [partim], pl. 2, figs. 11, 12a–c, 13a–d.
1948. *Streptelasma rusticum* (Billings). C. W. Wilson, pl. 19, figs. 26, 27.
1949. *Streptelasma rusticum* (Billings). C. W. Wilson, pl. 19, figs. 26, 27.
1963. *Streptelasma arcticum drummondense* Stumm, p. 27, pl. 2, figs. 4–7.
1964. *Grewingkia rustica* (Billings). Liberty, pl. 6, fig. 8.
1967. *Grewingkia rustica* (Billings). Oliver in Simmons and Oliver, pp. 9, 10.
1967. “*Streptelasma*” spp. A–E and “*S.*” *angulatum* (Billings). Oliver in Simmons and Oliver, p. 10.
1972. *Grewingkia rustica* (Billings). Bolton and Copeland, pl. B, figs. 9, 11.
1978. *Grewingkia* sp. Copper, pl. 6, figs. 3, 4.

Lectotype (designated herein).—GSC 1983h, i; upper member of the Georgian Bay Formation; Drummond Island, Michigan; A. Murray collection, 1847 (Billings, 1862, fig. 93b; Pl. 10, figs. 9–11).

Paralectotypes (designated herein).—GSC 1983, 1983a; GSC 1983b, c, e (Billings, 1862, fig. 93c; Liberty, 1964, pl. 6, fig. 8; Bolton and Copeland, 1972, pl. B, fig. 11); GSC 1983d; GSC 1983f, g; upper member of the Georgian Bay Formation; Drummond Island, Michigan; A. Murray collection, 1847.

Other Specimens.—

UCGM 45153–45500; Richmond Group; Cincinnati Arch region of Ohio, Indiana, and Kentucky (see Text-fig. 3 for stratigraphic positions and locations); Elias collection.

USNM 311626, 311627; “Waynesville” strata (base of Clarksville beds) of the Richmond Group; near Clarksville, Ohio.

USNM 70487 (4 specimens); “Waynesville” strata (lower 1 m of Clarksville beds) of the Richmond Group; Stony Hollow, Clarksville, Ohio.

USNM 78749 (syntype of *S. vagans*); “Liberty” strata of the Richmond Group; Tate’s Hill, Dayton, Ohio.

USNM 84871 (2 specimens); “Liberty” or “Whitewater” strata of the Richmond Group; Tate’s Hill, Dayton, Ohio.

USNM 78742 (5 syntypes of *S. disbandum*); “Waynesville” strata (Blanchester beds) of the Richmond Group; Moore’s Hill, Indiana.

USNM 84870 (holotype of *S. insolitum*); “Whitewater” strata of the Richmond Group; southeast of Westport, Indiana.

USNM 9719 (9 specimens); “Waynesville” strata of the Richmond Group; railroad cut, Madison, Indiana.

USNM 15587; “Whitewater” strata of the Richmond Group; Connersville, Indiana.

USNM 311663–311716; Otter Creek coral bed, Preachersville Member, Drakes Formation (see Simmons and Oliver, 1967); USNM 311663–311666, USGS locality 4662-CO, Lancaster Quadrangle, Lincoln County, Kentucky; USNM 311667–311692, USGS locality D1370-CO, Richmond North Quadrangle, Madison County, Kentucky; USNM 311693, USGS locality 5308-CO, Union City Quadrangle, Madison County, Kentucky; USNM 311694–311704, USGS locality 4468-CO, Palmer Quadrangle, Estill County, Kentucky; USNM 311705–311710, USGS locality 4545-CO, Palmer Quadrangle, Madison County, Kentucky; USNM 311711–311716, USGS locality 4760-CO, Palmer Quadrangle, Clark County, Kentucky.

UCGM 45501–45536; Richmond Group; Goodlettsville-Gallatin area of Tennessee (see Text-fig. 3 for stratigraphic positions and locations); Elias collection.

USNM 102371 (7 specimens); Arnheim Formation

(*Rhynchotrema dentatum* bed, middle division of Richmond Group); 6.4 km northeast of Goodlettsville, Tennessee.

USNM 42512 (21 specimens); 6.4 km northeast of Goodlettsville, Tennessee.

USNM 311647–311652; Bassler's bed 5, Richmond Group; near Bakers, Tennessee.

USNM 80609; Arnheim Formation; near Bakers, Tennessee.

USNM 42515 (13 specimens); Arnheim Formation; 0.8 km south of Dismukes, Sumner County, Tennessee.

USNM 311653; colonial coral bed at top of Maquoketa Group; NW¼, sec. 17, T27N, R24E, Little Sturgeon Bay, Wisconsin; Ulrich collection.

USNM 311654–311659 (*G. cf. G. canadensis*); colonial coral bed at top of Maquoketa Shale; Little Sturgeon Bay, Wisconsin; Ulrich and Mesler collection.

UCGM 45537–45562, 45612; upper Meaford beds, upper member of the Georgian Bay Formation; Drummond Island, Michigan (see Text-fig. 18 for stratigraphic positions and locations); Elias collection.

UMMP 26927, 45353, 45354 (holotype and paratypes, respectively, of *S. arcticum drummondense*); upper Meaford beds, upper member of the Georgian Bay Formation; south side of Potaganissing Bay, Poe Point, Drummond Island, Michigan; Hussey collection.

UCGM 45563–45591; Meaford beds, upper member of the Georgian Bay Formation; Manitoulin Island, Ontario (see Text-fig. 18 for stratigraphic positions and locations); Elias collection.

GSC 66622–66634; upper Wekwemikongsing beds, lower member of the Georgian Bay Formation; locality M75, Manitoulin Island, Ontario (see Text-fig. 18 for stratigraphic position and location).

GSC 66637–66649; Meaford beds, upper member of the Georgian Bay Formation; locality M61a, Manitoulin Island, Ontario (see Text-fig. 18 for stratigraphic position and location).

GSC 8530, 8530a–c, e–j (10 specimens); Meaford beds, upper member of the Georgian Bay Formation; gully north of lighthouse, Manitowaning, Manitoulin Island, Ontario; Foerste collection.

GSC 8529, 8529b–d (4 specimens); GSC 8528, 8528a–d (5 specimens); GSC 8573a–c (3 specimens); GSC 66589; Meaford beds, upper member of the Georgian Bay Formation; GSC locality 6259, Clay Cliffs, Manitoulin Island, Ontario; Foerste collection.

GSC 1982, 1982a; GSC 1982b, c; GSC 1982d, e; GSC 1982f, g; GSC 1982i; GSC 1982k, l; Meaford beds, upper member of the Georgian Bay Formation;

Cape Smith, Manitoulin Island, Ontario; R. Bell collection, 1859.

GSC 8531; upper Georgian Bay Formation; 3.2 km northwest of Meaford on road to Cape Rich, Ontario; Foerste collection.

Occurrence.—Upper Ordovician (Richmondian): “Waynesville” strata to top of Richmond Group; Cincinnati Arch region of Ohio, Indiana, and Kentucky, U.S.A. Throughout the Richmond Group; Goodlettsville-Gallatin area of Tennessee, U.S.A. Meaford beds, upper member of the Georgian Bay Formation; Drummond Island, Michigan, U.S.A. Top of lower member (Wekwemikongsing beds), and Meaford beds of upper member, Georgian Bay Formation; Manitoulin Island, Ontario, Canada. Top of Georgian Bay Formation; Meaford, Ontario, Canada. Top of Maquoketa Group; Little Sturgeon Bay, Wisconsin, U.S.A.

Diagnosis.—Axial region highly variable in late stage, ranging from very complex axial structure with many septal lobes and lamellae, to simple structure with only a few septal lobes, to open axial region lacking septal elements—moderately complex axial structure with septal lobes and lamellae is most common. Major septa completely dilated in early stage, greatly to completely dilated in intermediate stage, and non-dilated to slightly dilated in late stage. Cardinal and counter septa generally distinct, longer than the other septa throughout ontogeny and commonly with greatly dilated lobes in intermediate stage.

Description of Corals.—The corals can attain lengths in excess of 130 mm, and diameters greater than 40 mm. The length of specimens is shown in Text-figure 6 (see discussion under “Cincinnati Arch Region”). The corals vary from ceratoid to trochoid in early stages, and commonly become cylindrical in late stages. They are generally slightly curved in early to intermediate stages and are straight in late stages. Moderately curved specimens are uncommon. Wells (1970, p. 9) reported about 412 daily growth lines per year for a well preserved coral from Ohio that probably belongs to this species. Septal grooves and interseptal ridges are preserved on the epitheca of some specimens. Corals in lateral contact are very rare (USNM 15587, Pl. 9, fig. 17; UCGM 45307, 45438, 45533, 45577). Asexual increase has not been demonstrated in these cases. Depth of the calice commonly is about 35 percent of the coral length, but varies from 30 to 50 percent. The calicular boss is moderately convex when an axial structure is developed (Pl. 9, fig. 19s).

Ontogeny and Internal Structures.—In early stages the major septa extend to or almost to the axis. In

intermediate stages the small axial structure is composed of a few greatly dilated septal lobes, and the cardinal and counter septal lobes are often especially prominent (for example, Pl. 9, fig. 12). In late stages the axial region is highly variable. The axial structure is generally of moderate size and complexity, consisting of septal lobes and lamellae, but it varies from very complex with many fine septal lamellae to simple with only a few septal lobes. Septal elements are completely lacking in some specimens, resulting in an open axial region (Pl. 7, figs. 1–21; Text-fig. 12).

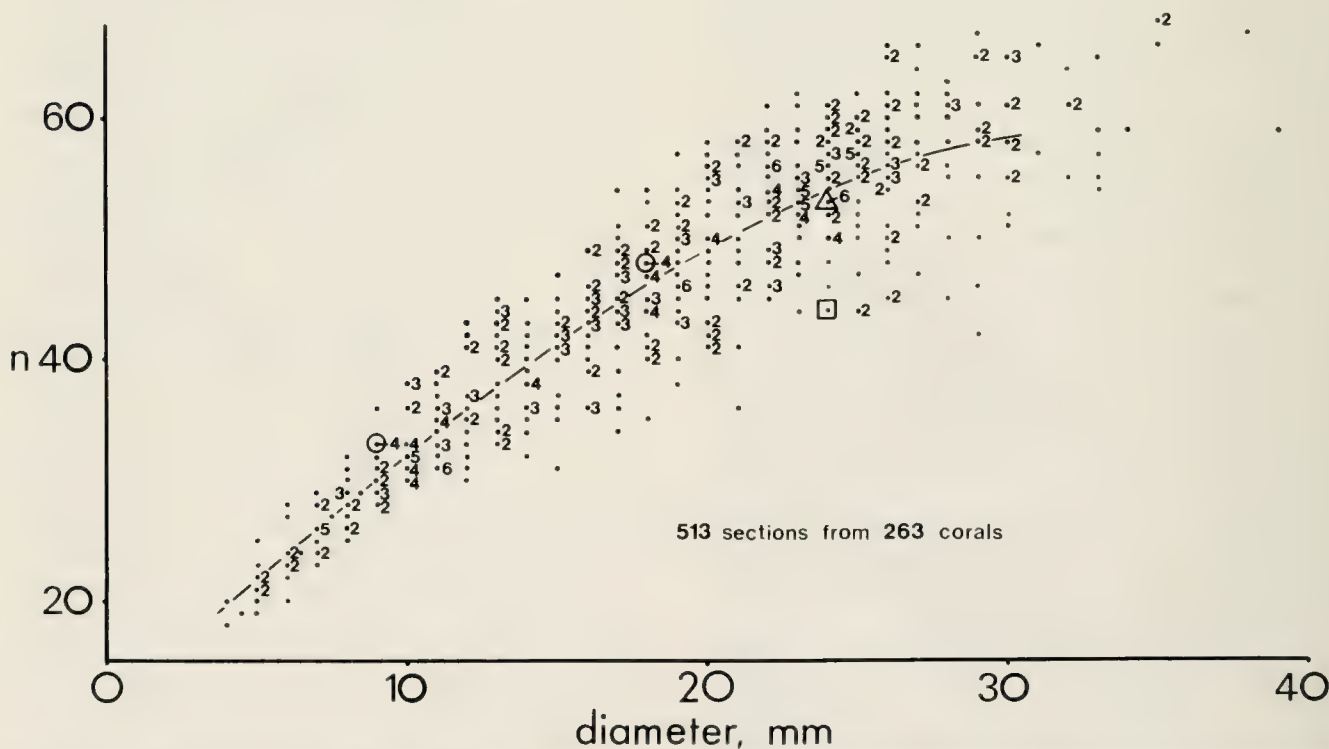
The number of major septa at a particular diameter is shown in Text-figure 33. The major septa are completely dilated in early stages, greatly to completely dilated in intermediate stages, and non-dilated to slightly dilated in late stages. The cardinal and counter septa commonly are distinct in being longer than the other septa throughout ontogeny (for example, Pl. 8, figs. 26–29, Pl. 7, fig. 12). The cardinal fossula in late stages is narrow and expands at the axial region. The minor septa are generally confined to the moderately broad stereozone in late stages.

Tabellae are present in the septal region in incom-

pletely dilated stages (for example, Pl. 8, fig. 30), and in the cardinal fossula. They are steeply to moderately inclined up toward the axis in intermediate stages and become less steeply inclined with increased height in the coral. The tabulae in the axial region are mostly complete and generally moderately spaced. In intermediate stages they are moderately to highly convex upward, and in late stages are commonly moderately convex.

Microstructure.—The major septa are clearly fibrous, especially when dilated. Trabeculae are inclined slightly up toward the axis. The stereozone in incompletely dilated sections is composed of lamellae. The epitheca consists of small groups of fibers that commonly are oriented perpendicular to the exterior surface.

Discussion.—The syntypes of *Zaphrentis canadensis* are from Drummond Island, where corals are unfortunately not as well preserved as elsewhere in the Richmond Province. However, these and other specimens from Drummond Island are indistinguishable from specimens at Manitoulin Island, the Cincinnati Arch region, and northern Tennessee. One specimen



Text-figure 33.—Relation between number of major septa (n) and coral diameter in *Grewinkia canadensis* (Billings, 1862) from the entire Richmond Group, Cincinnati Arch region. Numbers indicate frequency of a point if greater than one. Curve determined by inspection using class averages.

△ = USNM 78749a [syntype of *Streptelasma vagans* Foerste (1909)], "Liberty" strata, Dayton, Ohio.

□ = USNM 78742a [syntype of *S. dispanum* Foerste (1909)], "Waynesville" strata, Moore's Hill, Indiana.

○ = USNM 84870a, b [holotype of *S. insolitum* Foerste (1909)], "Whitewater" strata, Westport, Indiana.

(GSC 1983*h*, *i*) from Billings' syntypes is designated as the lectotype of *Grewingkia canadensis* (Billings, 1862) because it was figured in the original description and transverse sections have been prepared.

The Late Ordovician solitary corals from Drummond Island were assigned to *Streptelasma corniculum* by Nicholson (1875*b*) and Rominger (1876), to *S. rusticum* by Lambe (1901) and Cox (1937), and to *G. rustica* by Liberty (1964) and Bolton and Copeland (1972). Solitary corals from Manitoulin Island were assigned to *S. corniculum* by Nicholson (1875*a*), *S. rusticum* by Lambe (1901), Foerste (1924), and Cox (1937), and *G. rustica* by Bolton and Copeland (1972). All these corals are *G. canadensis*. Stumm (1963) described *S. arcticum drummondense* from Drummond and Manitoulin Islands. The holotype, which has been sectioned (Pl. 10, figs. 15–17), and figured paratypes are *G. canadensis*. The large solitary corals from the Cincinnati Arch region were assigned to *S. corniculum* by Milne-Edwards and Haime (1851), Nicholson (1875*b*, 1876), Rominger (1876), and Hall (1882), and to *S. rusticum* by Cumings (1908) and Cox (1937). Foerste (1909) described *S. vagans*, *S. insolitum*, and *S. dispanum*, distinguishing them primarily on the basis of external form. In 1924, he synonymized *S. vagans* with *S. rusticum* and reported *S. dispanum* from Manitoulin Island. His types have been sectioned, and are *G. canadensis* (Pl. 9, figs. 13–16). Oliver (in Simmons and Oliver, 1967) reported *G. rustica*, "*Streptelasma*" spp. A–E and "*S.*" *angulatum*. These specimens have been examined, and represent various growth stages and variations of *G. canadensis*. Bassler (1932) and C. W. Wilson (1948, 1949) assigned solitary corals from northern Tennessee to *S. rusticum*. These are *G. canadensis*. Foerste (1924) identified a specimen from Meaford, Ontario, as *S. rusticum*. This coral has been sectioned and is *G. canadensis* (Pl. 10, fig. 28). Specimens from Little Sturgeon Bay are silicified and poorly preserved, but one (USNM 311653) can be assigned to *G. canadensis* (Pl. 10, fig. 8).

The degree of axial region variation in later ontogenetic stages within *G. canadensis* spans the genera *Borelasma*, *Helicelasma*, and *Grewingkia* as they are presently defined. The species is referred to *Grewingkia* because the majority of corals have a moderately complex axial structure characteristic of that genus. *G. rustica* (Billings, 1858*a*), known from the Richmond Group at Lake St. John, Québec, and Manitoulin Island, Ontario, is similar to *G. canadensis* in external form, and the two species may be related. *G. canadensis* is distinguished by its cardinal and counter septa that commonly are longer than the other septa

throughout ontogeny and have greatly dilated lobes in intermediate stages. In *G. rustica*, the major septa generally form a counterclockwise whorl in early to intermediate stages, and septal dilation is complete to great until immediately below the calice in late stages, where dilation decreases and a complex axial structure develops. The number of major septa at a particular diameter for *G. rustica* is at the low end of the range of values for *G. canadensis* (Text-figs. 33, 35). *G. canadensis* resembles species of *Grewingkia* from the continental interior of the Red River–Stony Mountain Province in having well developed tabellae in the septal region (see Elias, 1981).

Grewingkia deltensis n. sp.

Plate 11, figures 1–11

1918. *Streptelasma rusticum* (Billings). Foerste, p. 99, pl. 4, fig. 1.
1963. *Streptelasma rusticum* (Billings). Stumm, pp. 26, 27 [*partim*], pl. 2, figs. 1–3, non pl. 2, figs. 8–10.

Derivation of Name.—The specific name is derived from Delta County, Michigan, where the species occurs.

Holotype.—UCGM 45602; Ogontz Member of the Stonington Formation; locality 17*b*, Delta County, Michigan; Elias collection (Pl. 11, figs. 1–8).

Paratypes.—UMMP 26911; Bay de Noc Member of the Stonington Formation; locality 17*b*, Delta County, Michigan (Stumm, 1963, pl. 2, figs. 1–3). UCGM 45593–45595, 45596 (Pl. 11, figs. 9–11), 45597–45601, 45603, 45604; Ogontz Member of the Stonington Formation; locality 17*b*, Delta County, Michigan; Elias collection.

Occurrence.—Upper Ordovician (Richmondian): Bay de Noc and Ogontz Members of the Stonington Formation; Delta County, Michigan, U.S.A.

Diagnosis.—*Grewingkia* with moderately complex axial structure of septal lobes and lamellae in late stage. Major septa almost completely dilated in early stage and non-dilated in late stage. Cardinal septum becomes short, cardinal fossula prominent and broad in late stage. Tabulae slightly convex upward within septal and axial regions but concave upward at junction of the two regions.

Description of Corals.—The longest specimen examined (UCGM 45604) has a length of 85 mm and diameter of 33 mm immediately below the calice where 59 major septa are present. Another specimen (UMMP 26911) is 81 mm long and has a diameter of 37 mm immediately below the calice where 62 major septa are present. The corals are trochoid and moderately curved. Septal grooves and interseptal ridges are present on the epitheca (UCGM 45594). Depth of the calice is 30 percent of the coral length (UMMP 26911;

UCGM 45602, 45604). The calicular boss is slightly convex (UCGM 45602, Pl. 11, fig. 7).

Ontogeny and Internal Structures.—Near the tip, some major septa extend to the axis. In intermediate stages a few long septal lobes arising primarily from septa on the cardinal side extend to the axis. In late stages the major septa become short and the large axial region contains a moderately complex structure of generally thin septal lobes and lamellae.

The number of major septa at a particular diameter is shown in Text-figure 34. Near the tip the major septa are almost completely dilated. Dilation decreases upward. Septal dilation in some specimens is greater on the cardinal side than on the counter side (Pl. 11, figs. 3, 11). In early stages the cardinal septum is long and thicker than the other septa (Pl. 11, figs. 2, 3). In intermediate stages it becomes thinner than the other septa and the fossula is narrow. In late stages the cardinal septum becomes short, and a broad, prominent fossula develops (Pl. 11, figs. 4, 5). In early to intermediate stages the major septa on the cardinal side tend to impinge on the cardinal septum or fossula, and septa on the counter side tend to impinge on the long alar septa. The minor septa are poorly developed and confined to the narrow stereozone.

Tabulae first appear when the axial region begins to develop. They are mostly complete and very closely to widely spaced. The tabulae are slightly convex upward within the septal and axial regions, but are concave upward at the junction of the two regions (Stumm, 1963, pl. 2, fig. 2). They are depressed in the

cardinal fossula. A few complementary plates (see B. Neuman, 1969, p. 6) are present.

Microstructure.—Septal fibers are well developed, and the trabeculae are slightly inclined up toward the axis. Lamellae are rarely present in the stereozone.

Discussion.—Foerste (1918) reported *Streptelasma rusticum* in the Ogontz Member and immediately beneath in the Bay de Noc Member of the Stonington Formation in Delta County, Michigan. Stumm (1963) described and illustrated a single specimen from the Bay de Noc Member in the same area and assigned it to *S. rusticum*. These specimens are *Grewingkia deltensis* n. sp.

G. deltensis is distinguished from other species of the genus by its broad, prominent cardinal fossula with short cardinal septum in late stages, and tabulae that are convex upward within the septal and axial regions but concave upward at the junction of the two regions. It resembles species of this genus from the continental interior of the Red River–Stony Mountain Province in being trochoid and moderately curved (see Elias, 1981).

Grewingkia rustica (Billings, 1858a)

Plate 11, figures 12–29

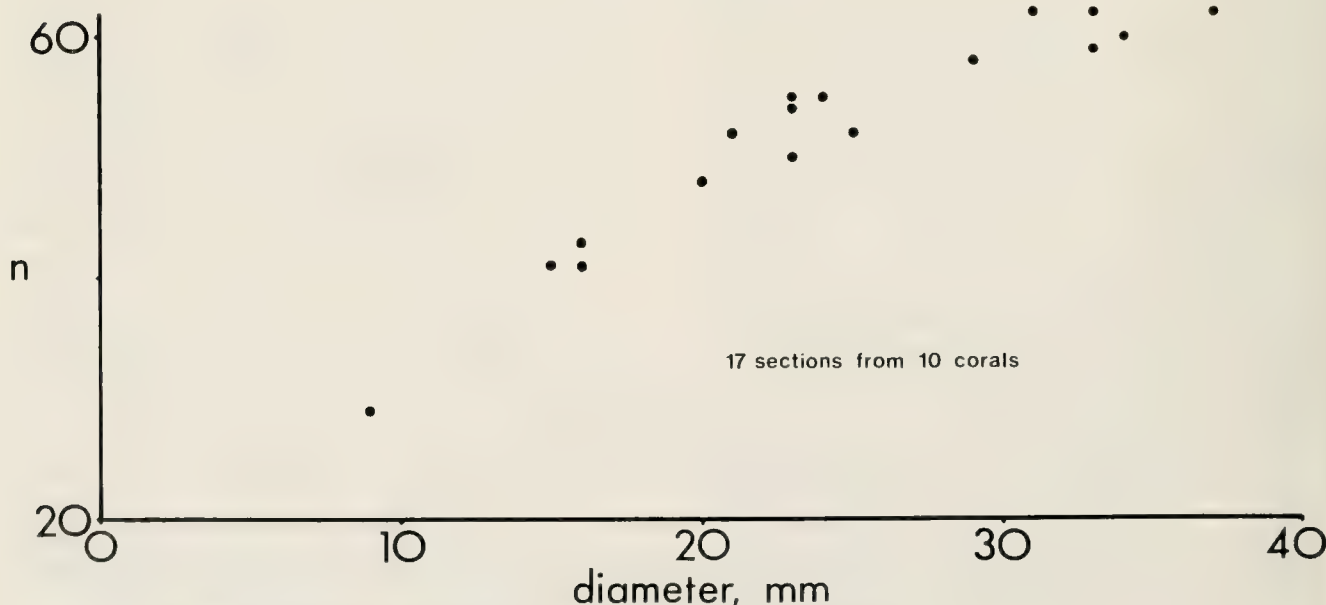
1858a. *Petraia rustica* Billings, pp. 168, 169.

1858b. *Petraia rustica* Billings, pp. 422, 423.

1901. *Streptelasma rusticum* (Billings). Lambe, pp. 110–112 [partim], pl. 7, figs. 2, 2a, 3.

1908. *Streptelasma rusticum* (Billings). Cumings, pp. 708, 709 [partim], non pl. 2, fig. 2, 2a, 2b.

1924. *Streptelasma rusticum* (Billings). Foerste, pp. 65, 66 [partim], non pl. 1, figs. 1a–c, 2a–c, pl. 2, fig. 6a–c.



Text-figure 34.—Relation between number of major septa (n) and coral diameter in *Grewingkia deltensis* n. sp.

1937. *Streptelasma rusticum* (Billings). Cox, pp. 11–13 [partim], non pl. 2, figs. 11, 12a–c, 13a–d.

1963. *Streptelasma rusticum* (Billings). Stumm, pp. 26, 27 [partim], pl. 2, figs. 8–10, non pl. 2, figs. 1–3.

Lectotype (designated herein).—GSC 5822b, c; Snake Island, Lake St. John, Québec; J. Richardson collection, 1857 (Lambe, 1901, [?] pl. 7, fig. 3; Pl. 11, fig. 12).

Paralectotype (designated herein).—GSC 5822, 5822a; Snake Island, Lake St. John, Québec; J. Richardson collection, 1857 (Lambe, 1901, pl. 7, fig. 2, 2a).

Other Specimens.—

GSC 8527, 8527a, c, e, f, h, j–s (16 specimens), and UMMP 45351, 45352; Snake Island, Lake St. John, Québec; Foerste collection.

UCGM 45592; Meaford beds, upper member of the Georgian Bay Formation; locality 19b, Manitoulin Island, Ontario; Elias collection.

Occurrence.—Upper Ordovician (Richmondian): Richmond Group; Snake Island, Lake St. John, Québec, Canada. Meaford beds, upper member of the Georgian Bay Formation; Manitoulin Island, Ontario, Canada.

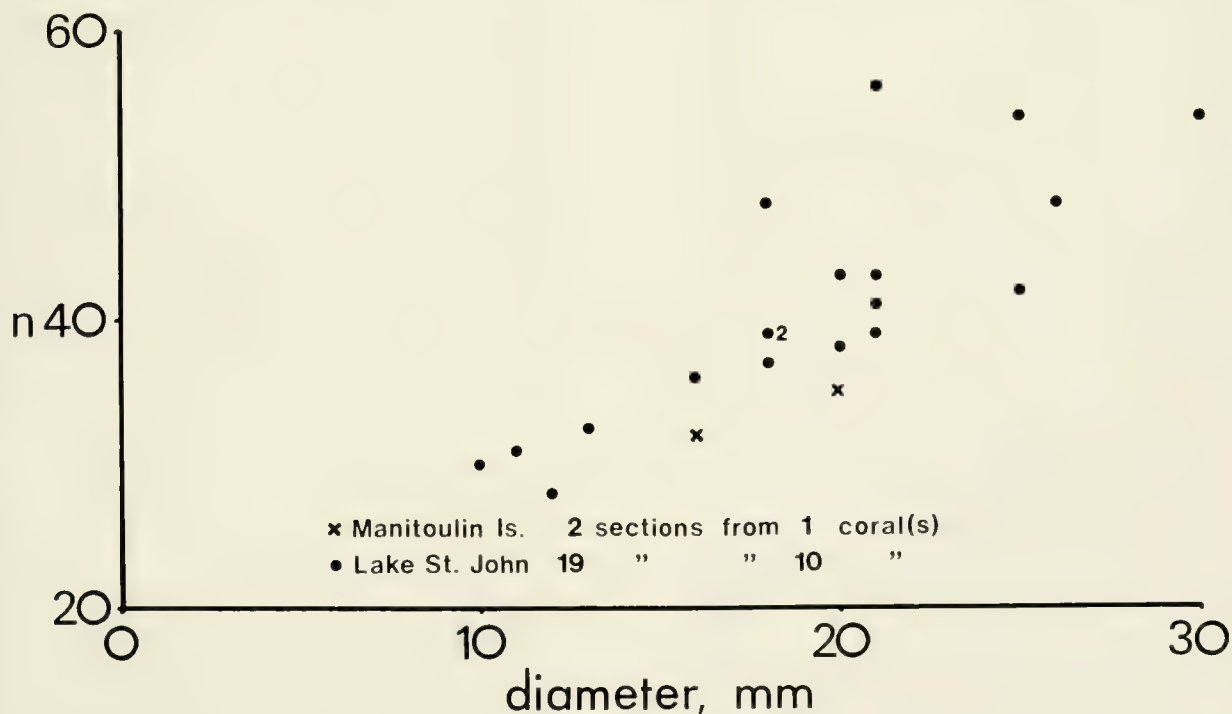
Diagnosis.—*Grewingkia* with complex axial structure of numerous septal lobes and lamellae in late stage immediately below calice. Major septa completely dilated in early stage and greatly dilated in later stages until immediately below calice, where dilation of septa

and axial structure decreases. Major septa generally form counterclockwise whorl in early and intermediate stages.

Description of Corals.—The largest specimen examined (GSC 5822b, c) has a length of 65 mm but is incomplete at both ends. It has a diameter of 30 mm immediately below the calice where 54 major septa are present. The corals are ceratoid to trochoid in early stages, and become cylindrical in later stages. They are straight to slightly curved. Septal grooves and interseptal ridges are present on the epitheca. Depth of the calice is 40 percent of the coral length (GSC 5827l, n). The sides of the calice are steep and the boss is slightly convex (GSC 5827a, Pl. 11, fig. 28s).

Ontogeny and Internal Structures.—In early stages the major septa extend to or almost to the axis. A few greatly dilated septal lobes soon appear, followed by septal lamellae. A large, complex axial structure of numerous septal lobes and lamellae is developed in later stages in the less dilated zone immediately below the calice.

The number of major septa at a particular diameter is shown in Text-figure 35. The major septa are completely dilated in early stages and remain greatly dilated in later stages until immediately below the calice, where dilation of the septa and axial structure decreases. In early stages the cardinal septum is long and commonly is thicker than the other major septa.



Text-figure 35.—Relation between number of major septa (n) and coral diameter in *Grewingkia rustica* (Billings, 1858a). Numbers indicate frequency of a point if greater than one.

In intermediate and late stages it becomes thinner and a narrow fossula develops. In most specimens the major septa form a counterclockwise whorl in early to intermediate stages (Pl. 11, figs. 22, 23, 26, 27, 28s; see Laub, 1978). In later stages the minor septa are confined to or extend a short distance beyond the moderately broad stereozone.

Tabulae, first appearing in intermediate stages, are mostly complete and moderately to widely spaced. They vary from slightly depressed axially (UMMP 45352, Stumm, 1963, pl. 2, fig. 10), to slightly convex upward (GSC 5822, 5822a, Lambe, 1901, pl. 7, fig. 2a), to highly convex upward (GSC 8527j, Pl. 11, fig. 13). A few complementary plates (see B. Neuman, 1969, p. 6) are present.

Microstructure.—Septal fibers are well developed, and trabeculae are slightly inclined up toward the axis. Lamellae are not present in the stereozone.

Discussion.—Solitary corals from Snake Island, Lake St. John, Québec, were first listed as *Streptoplasma corniculum* by Richardson (1858, p. 89). Billings (1858a, 1858b) described Richardson's specimens as a new species, *Petraia rustica*, but did not provide figures. Lambe (1901) examined the types and figured two corals that had been collected at Snake Island by Richardson in 1857. These were almost certainly Billings' syntypes, and are herein designated as the lectotype and paralectotype. Only those portions of the descriptions and illustrations in Lambe (1901), Cumings (1908), Foerste (1924), Cox (1937), and Stumm (1963) dealing with specimens from Snake Island are synonymous with *Grewingkia rustica* (Billings, 1858a). Their other material and all references to this species not included in the synonymy belong to other species.

G. canadensis (Billings, 1862), a widespread Richmond Group species, is similar to *G. rustica* in external form, and the two may be related. *G. rustica* is distinct in having major septa that generally form a counterclockwise whorl in early to intermediate stages, and are completely to greatly dilated until immediately below the calice in late stages, where dilation decreases and a complex axial structure develops. The cardinal and counter septa in *G. canadensis* commonly are distinct, being longer than the other septa throughout ontogeny and having greatly dilated lobes in intermediate stages. The number of major septa at a particular diameter for *G. rustica* is at the low end of the range of values for *G. canadensis* (Text-figs. 33, 35).

One solitary coral from the base of the Meaford beds on Manitoulin Island, Ontario, has a thin, relatively short cardinal septum and a counterclockwise whorl in its latest stage (UCGM 45592, Pl. 11, fig. 27). The

number of septa at a particular diameter is lower than that for specimens of *G. canadensis* from Manitoulin Island (Text-figs. 20, 35). Because of these features, it is assigned to *G. rustica*, although the long cardinal and counter septa in the intermediate stage (Pl. 11, fig. 26) resemble *G. canadensis*. Except for this single specimen, *G. rustica* is known only from Lake St. John, Québec.

***Grewingkia penobscotensis* n. sp.**

Plate 12, figures 1–6

Derivation of Name.—The specific name refers to Penobscot County, Maine, where the species occurs.

Holotype.—USNM 311748; R. B. Neuman collection (Pl. 12, figs. 3–5).

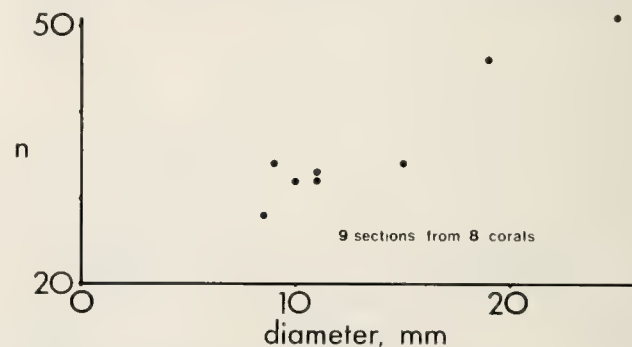
Paratypes.—USNM 311749, 311750, 311751 (Pl. 12, figs. 1, 2), 311752–311756, 311757 (Pl. 12, fig. 6); R. B. Neuman collection.

Occurrence.—Upper Ordovician (Ashgill): About 520 m above base of unnamed formation; between Pond Pitch and Haskell Rock Pitch, East Branch, Penobscot River, Penobscot County, Maine, U.S.A.

Diagnosis.—*Grewingkia* with coarse axial structure that develops early in ontogeny and consists of a few moderately dilated septal lobes and lamellae. Major septa slightly dilated to non-dilated during ontogeny. Cardinal septum indistinct, cardinal fossula not developed. Calicular boss prominent.

Description of Corals.—The specimens are poorly preserved and incomplete. The largest coral examined (USNM 311748) has a diameter of 25 mm and 51 major septa in the calice. The corals are ceratoid to trochoid and slightly curved. The calicular boss is prominent (Pl. 12, figs. 1, 3).

Ontogeny and Internal Structures.—A coarse axial structure of a few moderately dilated septal lobes and lamellae appears early in ontogeny. The number of major septa at a particular diameter is shown in Text-figure 36. The major septa are non-dilated to slightly dilated. The cardinal septum is indistinct and a fossula



Text-figure 36.—Relation between number of major septa (n) and coral diameter in *Grewingkia penobscotensis* n. sp.

is not developed. The minor septa extend a short to moderate distance beyond the moderately broad stereozone. The tabulae are somewhat irregular, mostly complete, and moderately convex upward (Pl. 12, fig. 1). Tabulae are concave upward at the periphery of the coral in only one specimen (USNM 311748, Pl. 12, fig. 3). Complementary plates (see B. Neuman, 1969, p. 6) are present in some specimens.

Microstructure.—The specimens are poorly preserved, but some weakly developed septal fibers can be distinguished, and weak trabeculae are inclined up toward the axis.

Discussion.—*Grewingkia penobscotensis* n. sp. is distinguished from other species of the genus by its non-dilated to slightly dilated septa, coarse axial structure of a few septal lobes and lamellae, indistinct cardinal septum, and lack of a fossula.

***Grewingkia pulchella* (Billings, 1865)**

Plate 12, figures 7–21

1865. *Petraia pulchella* Billings, pp. 429, 430.

1865. *Petraia selecta* Billings, p. 429 [partim].

1866. *Petraia pulchella* Billings. Billings, p. 33.

1866. *Petraia selecta* Billings. Billings, p. 7 [partim].

1901. *Streptelasma selectum* (Billings). Lambe, p. 113 [partim], pl. 6, fig. 8, 8a.

1928. *Streptelasma selectum* (Billings). Twenhofel, p. 113 [partim].

Lectotype (designated herein).—GSC 2243, 2243a; Ellis Bay Formation; Ellis Bay, Anticosti Island, Québec; T. C. Weston collection, 1865 (Lambe, 1901, pl. 6, fig. 8, 8a).

Other Specimens.—

(All from Twenhofel collection, Anticosti Island, Québec, unless otherwise stated.)

YPM 28723; Twenhofel's zone 5, upper member of the Vauréal Formation; zone 8 of Twenhofel's Vauréal River section.

GSC 1989e; GSC 1989h; GSC 1989i, j; GSC 1989k; GSC 1989l; GSC 1989m; GSC 1989n; upper member, 27 to 30 m below top of Vauréal Formation; west end lighthouse; J. Richardson collection, 1856 (probably syntypes of *Petraia selecta*).

YPM 28724, 28725; upper member (English Head facies) of the Vauréal Formation; West Bay.

YPM 28726–28728; Ellis Bay Formation; Cape James Bay.

YPM 28729, 28730; Ellis Bay Formation; west side of Prinsta Bay.

YPM 28731–28733; Ellis Bay Formation; west side of Ellis Bay.

YPM 28734; Ellis Bay Formation; cliff 1.2 km east of Junction Cliff.

YPM 28735; Ellis Bay Formation; Prinsta Bay.

YPM 28736; Ellis Bay Formation; Twenhofel's zone 13 at Cape James.

YPM 28737; Ellis Bay Formation; zone 15 of Twenhofel's Vauréal River section.

YPM 28738; Ellis Bay Formation; zone 22 of Twenhofel's Vauréal River section.

YPM 28739; Ellis Bay Formation; Twenhofel's zone D, west side of Ellis Bay.

YPM 28740; basal unit, Ellis Bay Formation; zone 10 of Twenhofel's Vauréal River section.

YPM 28721; upper Ellis Bay Formation; cliff between Bear Cape and Cape Eagle.

YPM 28741–28745; Twenhofel's zone 1, Ellis Bay Formation; Junction Cliff.

YPM 28746; Twenhofel's zone 1, Ellis Bay Formation; west side of Ellis Bay.

YPM 28747; Twenhofel's zone 2, Ellis Bay Formation; Junction Cliff.

YPM 28748–28750; Twenhofel's zone 2, Ellis Bay Formation; Junction Cliff.

YPM 28751; Twenhofel's zone 2, Ellis Bay Formation; west side of Ellis Bay.

YPM 28752; Twenhofel's zone 6, Ellis Bay Formation; east of Junction Cliff.

YPM 28753; Twenhofel's zone 7 (*Hormotoma gigantea* zone), Ellis Bay Formation; Ellis Bay.

YPM 28754, 28755; Twenhofel's zone 8, Ellis Bay Formation; west side of Ellis Bay.

YPM 28756; Twenhofel's zone 9, Ellis Bay Formation; reef at Ellis Bay.

YPM 28757; Twenhofel's zone 9, bioherm at base of Bolton's member 6, Ellis Bay Formation; Raspberry Point.

YPM 28758–28760; Twenhofel's zone 9, Ellis Bay Formation; Ellis Bay.

YPM 28761; Twenhofel's zone 10, Ellis Bay Formation; west side of Ellis Bay.

YPM 28722; Bolton's member 6, Ellis Bay Formation; Cape Eagle.

USNM 311717–311735; unnamed unit; USGS locality 4112-CO, 9 km east of Ashland, Maine; R. B. Neuman collection.

Occurrence.—Upper Ordovician: Upper member (lower to middle Ashgill) of the Vauréal Formation, and Ellis Bay Formation (Ashgill; Gamachian); Anticosti Island, Québec, Canada. Unnamed unit (Ashgill); 9 km east of Ashland, Maine, U.S.A.

Diagnosis.—*Grewingkia* with relatively small axial structure of completely dilated septal lobes in intermediate stage, and a few moderately to greatly dilated septal lobes and lamellae in late stage. Major septa completely dilated in early stage and slightly to moderately dilated in later stages.

Diagnosis.—Coral solitary, trochoid, and attains very large size. Cross-section trilobate. Calice of moderate depth with slightly convex calicular boss.

Cardinal septum on convex side of coral. Major septa completely dilated until immediately below calice. Minor septa poorly developed. Axial structure in latest stage comprises greatly to completely dilated septal lobes or lobes and lamellae. Tabellae in septal region. Tabulae in axial region mostly complete and slightly concave to convex upward.

Species and Occurrences.—*Lobocorallium* is known from the Upper Ordovician of North America. The following species are included in the genus:

1895. *Streptelasma rusticum* var. *trilobatum* (= *L. trilobatum trilobatum*) Whiteaves, p. 113. Upper Ordovician (lower to middle Ashgill): Gunn and Penitentiary Members of the Stony Mountain Formation; Stony Mountain, Manitoba, Canada.

1928. *Zaphrentis vaurealensis* (= *L. trilobatum vaurealense*) Twenhofel, pp. 116, 117, pl. 3, fig. 1. Upper Ordovician (lower to middle Ashgill): Upper member of the Vauréal Formation; Anticosti Island, Québec, Canada. White Head Formation; Percé, Québec, Canada.

Discussion.—*Lobocorallium* was proposed by Nelson (1963) to include the trilobate corals *Streptelasma rusticum* var. *trilobatum*, *S. goniophylloides* Teichert (1937), and *L. trilobatum* var. *major* Nelson (1963). The latter two species have ontogenies and axial structures characteristic of *Grewingkia* Dybowski (1873), and have been assigned to *G. haysii* (Meek, 1865) by Elias (1981, p. 18). Trilobation appears within several species of *Grewingkia* and *Deiracorallium*, and its significance as a generic trait is uncertain, as was discussed under the latter genus. *Lobocorallium* is presently considered distinct in having completely dilated septa until immediately below the calice, where an axial structure of greatly to completely dilated septal lobes, or lobes and lamellae, is developed in late stages. *G. haysii* and *L. trilobatum vaurealense* are intermediate forms linking *Grewingkia* and *Lobocorallium*, as was discussed under the former genus.

Lobocorallium trilobatum vaurealense

(Twenhofel, 1928)

Plate 13, figures 1–7

1928. *Zaphrentis vaurealensis* Twenhofel, pp. 116, 117, pl. 3, fig. 1.

1980. *Lobocorallium vaurealensis* (Twenhofel). Bolton, pl. 2.4, figs. 4, 8, pl. 2.7, figs. 2, 3.

Holotype (by original designation).—YPM 20482; Twenhofel's zone 5, upper member of the Vauréal Formation; zone 7 of Twenhofel's Vauréal River section, Anticosti Island, Québec; Twenhofel collection (Twenhofel, 1928, pl. 3, fig. 1; Pl. 13, figs. 1s, 2).

Other Specimens.—

GSC 66590, 66591; upper member, about 50 m below top of Vauréal Formation; GSC locality 36157, main highway section, cut approximately 10.4 km from Port Menier, Anticosti Island, Québec; Bolton collection.

GSC 53556; upper member of the Vauréal Formation; first creek before shore, Martin Bay road, Anticosti Island, Québec.

USNM 311635, GSC 53545; *Stenopareia* faunal zone, White Head Formation; Grande Coupe, 2.4 km northwest of Percé, Québec.

GSC 53546, 53547; unit 4 of White Head Formation; Flynn road, 1 km southwest of Percé, Québec.

Occurrence.—Upper Ordovician (lower to middle Ashgill): Upper member of the Vauréal Formation; Anticosti Island, Québec, Canada. White Head Formation; Percé, Québec, Canada.

Diagnosis.—Compressed *Lobocorallium* with relatively large, complex axial structure of septal lobes and lamellae in late stage. Axial structure and septa completely dilated until immediately below calice, where dilation is great.

Description of Corals.—The largest specimen examined has a length of 150 mm (YPM 20482, Pl. 13, fig. 1s). Another specimen (GSC 66591) has 71 major septa at a cross-sectional area of 1025 mm². The corals are trochoid and slightly to moderately curved. They are compressed throughout ontogeny, and the maximum cross-sectional length-width ratio is 1.3 (USNM 311635). In cross-section the corals are trilobate throughout ontogeny (Pl. 13, fig. 1s). Trilobation is most pronounced several cm above the tip, and decreases upward. Depth of the calice is 20 percent of the coral length (YPM 20482, Pl. 13, fig. 2). The calicular boss is slightly convex.

Ontogeny and Internal Structures.—In early stages the major septa extend to the axis. A few completely dilated septal lobes and lamellae appear in intermediate stages. In the latest stages the relatively large, complex axial structure consists of greatly dilated septal lobes and lamellae.

The number of major septa at a particular cross-sectional area is shown in Text-figure 38. The septa and axial structure are completely dilated until immediately below the calice (Pl. 13, figs. 5, 6). The cardinal septum is long, and a cardinal fossula generally is not developed. In early to intermediate stages the major septa on the cardinal side tend to impinge on the cardinal septum, and septa on the counter side tend to impinge on the long alar septa. Minor septa are poorly developed and often indistinct because of the completely dilated major septa.

Tabellae that are convex upward are present in the septal region. They are inclined up toward the axis in early stages and become less steeply inclined with increased height in the coral. They are oriented horizontally in late stages. Tabulae in the axial region are mostly complete, moderately spaced, often dilated, and approximately horizontal (Pl. 13, fig. 2).

Microstructure.—Septal fibers are well developed, and lamellae are present in the stereozone.

Discussion.—The following specimens of *Lobocorallium trilobatum trilobatum* (Whiteaves, 1895) from the Gunn and Penitentiary Members of the Stony Mountain Formation at Stony Mountain, southern Manitoba, have been examined (Elias, 1981, p. 12): GSC 6825 (collected by T. C. Weston in 1884; this specimen is probably a syntype), 60757, 60763–60771. *L. trilobatum vaurealense* (Twenhofel, 1928) differs in having less pronounced trilobation, a larger axial structure that is slightly less dilated in the latest stages and consists of septal lamellae in addition to lobes, and in possessing fewer major septa at a particular cross-sectional area (Text-fig. 38). If *L. trilobatum vaurealense* was the immediate ancestor of *L. trilobatum trilobatum*, it can be added to the possible evo-

lutionary sequence *Grewingkia robusta* (Whiteaves, 1896) → *G. haysii* (Meek, 1865) → *L. trilobatum vaurealense* → *L. trilobatum trilobatum* (see Elias, 1981, p. 6). *L. trilobatum vaurealense* could also have been a contemporary geographic variant of *L. trilobatum trilobatum*. It is closer to *L. trilobatum trilobatum* than to *G. haysii*, which is generally not as markedly trilobate and has less pronounced septal dilation and a better developed axial structure (see Elias, 1981, pp. 17, 18, pl. 5, figs. 1–15, pl. 6, figs. 1–12). These corals are therefore included in *Lobocorallium*, and are not considered sufficiently different from *L. trilobatum trilobatum* to constitute a separate species.

Genus *KENOPHYLLUM* Dybowski, 1873

1873. *Kenophyllum* Dybowski, p. 358.

1958. *Kenophyllum* Dybowski. Kaljo, pp. 22, 23.

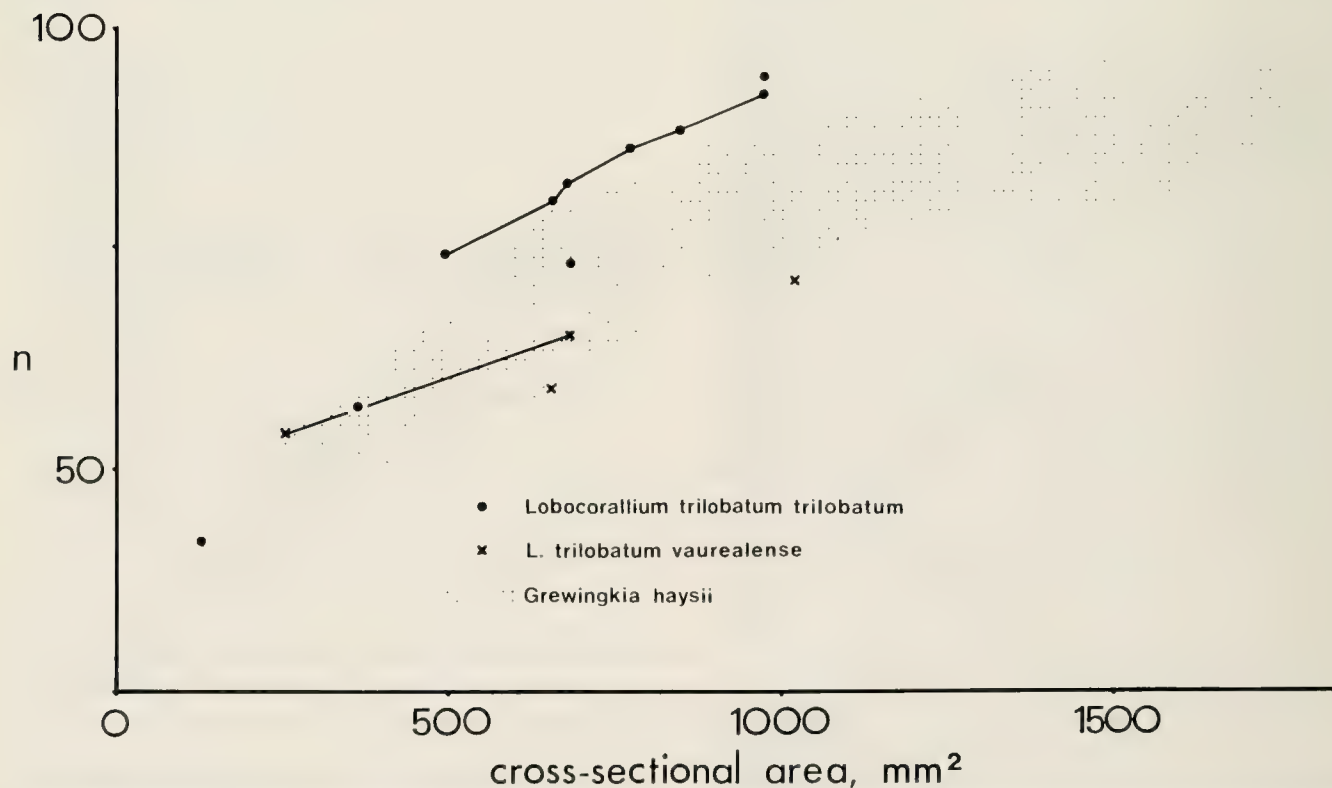
1961. *Kenophyllum* Dybowski. Kaljo, pp. 59, 60.

1977. *Kenophyllum* Dybowski. McLean, pp. 14, 15.

1977. *Kenophyllum* Dybowski. B. Neuman, pp. 74, 75.

Type Species (by monotypy).—*Kenophyllum subcylindricum* Dybowski (1873, p. 358). Vormsi Horizon (Upper Ordovician); Estonia.

Discussion.—*Kenophyllum* is presently considered



Text-figure 38.—Relation between number of major septa (n) and coral cross-sectional area in *Lobocorallium trilobatum trilobatum* (Whiteaves, 1895) from the Stony Mountain Formation, Stony Mountain, Manitoba; *Lobocorallium trilobatum vaurealense* (Twenhofel, 1928) from the Vauréal Formation, Anticosti Island, Québec, and the *Stenoparcia* faunal zone of the White Head Formation, Percé, Québec; *Grewingkia haysii* (Meek, 1865) from Manitoba, Northwest Territories, and northwestern Greenland (see Elias, 1981, fig. 11b).

distinct in having greatly to completely dilated septa throughout ontogeny, a dense axial structure of completely dilated septal lobes and lamellae, a cardinal fossula that commonly is prominent, and rare or absent tabulae. In the type species, the cardinal septum is almost always on the concave side of the coral, but also occurs on the convex side. This genus is known from the Upper Ordovician of Estonia and from questionable occurrences in the Ashgill (Upper Ordovician) of Maine and upper Llandovery (Lower Silurian) of western North Greenland.

Other authors have discussed the close relationship of *Kenophyllum* with *Leolasma* Kaljo (1956) (Scrutton, 1971, p. 211; B. Neuman, 1975, pp. 338–341; McLean, 1977, p. 15), *Grewingkia* Dybowski (1873) (B. Neuman, 1975, pp. 339, 340; 1977, p. 75), *Crasilasma* Ivanovskiy (1962) (McLean, 1977, p. 15), and *Pycnactis* Ryder (1926) (Kaljo, 1961, p. 60; see B. Neuman, 1977, p. 75).

Kenophyllum? sp.

Plate 13, figures 8, 9

Specimens.—USNM 311758, 311759; R. B. Neuman collection.

Occurrence.—Upper Ordovician (Ashgill): About 61 m above base of unnamed formation; between Pond Pitch and Haskell Rock Pitch, East Branch, Penobscot River, Penobscot County, Maine, U.S.A.

Description of Corals.—The largest specimen examined (USNM 311758) has a diameter of 18 mm and 37 major septa at an unknown distance below the calice. It is not known whether the cardinal septum occurs on the concave or convex side of the coral.

Ontogeny and Internal Structures.—In early stages the major septa extend to the axis. In later stages, a dense, solid axial structure of a few greatly dilated septal lobes and lamellae enclosed in stereoplasmatic deposits is present. In early stages, the septa are completely dilated. The major septa are greatly dilated in later stages, where the cardinal septum appears to be shorter than the others, creating a pronounced fossula. Minor septa are confined to the stereozone.

Microstructure.—The microstructure is unknown because the specimens are poorly preserved.

Discussion.—These two incomplete specimens appear to have the ontogeny and axial structure characteristic of *Kenophyllum*, but assignment to the genus remains questionable until the ontogeny is more completely known. The nature of the cardinal septum and fossula in late ontogenetic stages resembles *K. subcylindricum* Dybowski (1873) from the upper Caradoc–lower Ashgill (Upper Ordovician) of Estonia (Kaljo, 1961, pl. 4, fig. 6).

Genus *BODOPHYLLUM* B. Neuman, 1969

1969. *Bodophyllum* B. Neuman, pp. 54–56.

Type Species (by original designation).—*Bodophyllum osmundense* B. Neuman (1969, pp. 56–59). Boda Limestone (Upper Ordovician); Osmundsberg, Siljan district, Sweden.

Discussion.—*Bodophyllum*, as presently understood, is characterized by a dense to solid axial structure composed of septal lobes and very few lamellae, with a commonly prominent median lamella joining the cardinal and counter septa and forming a calicular boss (see B. Neuman, 1969, fig. 45). B. Neuman (1969, p. 56) reported this Upper Ordovician genus from Sweden and Norway, and noted probable occurrences in Scotland and North America. In North America it is present in the upper Upper Ordovician of the eastern Great Basin (Budge, 1977), in the Ashgill of Anticosti Island, Québec, and Maine, questionably in the lower to middle Ashgill at Percé, Québec, and in the ?Gamachian of Missouri.

Uncertainty concerning the relationship of *Bodophyllum* with other genera is indicated by the following points:

1. *Bodophyllum* is very similar to *Bighornia* Duncan (1957), but has the cardinal septum on the convex rather than concave side of the coral. However, some specimens of *Bighornia orvikui* Kaljo (1960) have a convex cardinal side, suggesting that the position of the cardinal septum may not be generically significant. Specimens of *Bighornia* are generally subcalceoloid in form, as is *Bodophyllum duncaniae* (Spjeldnaes, 1961).
2. The significance of a dilated median septal lamella in the axial structure is uncertain. *Grewingkia bilateralis* B. Neuman (1969), *G. lamellosa* Elias (1981), and some specimens of *Streptelasma cyrtum* B. Neuman (1969) also have a median lamella. In late ontogenetic stages of *Bodophyllum shorti* n. sp., the axial structure resembles that of *Grewingkia* because the median lamella is slightly dilated and irregular, and other septal lobes and lamellae are present.

McLean (1974, p. 43) suggested that *Bodophyllum*, *Bighornia*, *Dalmanophyllum* Lang and Smith (1939), and *Ditoecholasma* Simpson (1900) may be synonymous.

Bodophyllum shorti n. sp.

Plate 13, figures 10–14

Derivation of Name.—The species is named for the former owner of the farm on which this coral was found at the type section of the Leemon Formation.

Holotype and Only Specimen.—UCGM 45613; Elias collection (Pl. 13, figs. 10–14).

Occurrence.—Upper Ordovician (?Gamachian): Leemon Formation; locality 20a, Cape Girardeau County, Missouri, U.S.A.

Diagnosis.—*Bodophyllum* with solid axial structure in early stage and a prominent dilated median septal lamella in intermediate stage. In late stage a few septal lobes and lamellae are present in axial structure, and median lamella is slightly dilated, irregular, and not connected to cardinal or counter septa. Minor septa long, extending well beyond stereozone.

Description of Coral.—The coral is about 15 mm long and has a diameter of 8 mm a short distance below the calice where 34 major septa are present. It is straight. The base of attachment is on the cardinal side, and the specimen was attached to a bryozoan. Depth of the calice is about 40 percent of the coral length.

Ontogeny and Internal Structures.—The axial structure is solid in early stages. In intermediate stages a prominent dilated median septal lamella is connected to the long cardinal and counter septa and a few dilated septal lobes and rare septal lamellae are present. In late stages the elements of the axial structure are slightly dilated. The median lamella is irregular and discontinuous, and is not connected to the cardinal or counter septa. A few other septal lamellae and septal lobes are present. The major septa are slightly dilated in early stages, and non-dilated in later stages. A cardinal fossula is not developed. The minor septa are long, extending well beyond the narrow stereozone. Tabulae are present.

Microstructure.—Septal fibers are present. Lamellae apparently are not developed in the stereozone.

Discussion.—*Bodophyllum shorti* n. sp. has a solid axial structure in early stages, and a prominent dilated median septal lamella plus a few septal lobes and rare lamellae in intermediate stages. The species is assigned to *Bodophyllum* because of these characteristic features. However, in other species of the genus the dense to solid axial structure is present in late stages as well (see B. Neuman, 1969). *B. shorti* is distinct in having a slightly dilated axial structure in late stages, and long minor septa. *Streptelasma leemonense* n. sp., from the same locality, has very long minor septa but lacks an axial structure.

***Bodophyllum neumani* n. sp.**

Plate 14, figures 1–6

Derivation of Name.—The species is named for Robert B. Neuman, U.S. Geological Survey, who collected the specimens.

Holotype.—USNM 311760; R. B. Neuman collection (Pl. 14, figs. 3, 4).

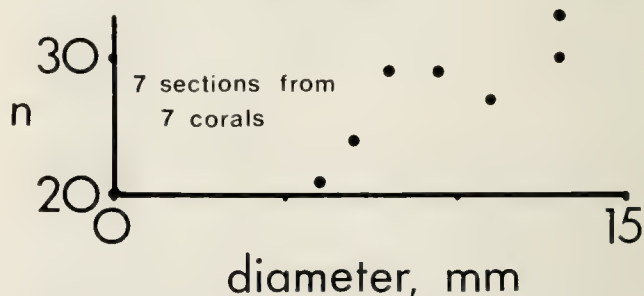
Paratypes.—USNM 311761 (Pl. 14, fig. 1), 311762 (Pl. 14, figs. 5, 6), 311763, 311764 (Pl. 14, fig. 2), 311765, 311766; R. B. Neuman collection.

Occurrence.—Upper Ordovician (Ashgill): About 520 m above base of unnamed formation; between Pond Pitch and Haskell Rock Pitch, East Branch, Penobscot River, Penobscot County, Maine, U.S.A.

Diagnosis.—*Bodophyllum* with prominent, elongate, dilated median septal lamella and a few septal lobes forming axial structure in all known ontogenetic stages.

Description of Corals.—The largest specimen examined (USNM 311762) has a diameter of 13 mm and 30 major septa at an unknown distance below the calice. The corals are ceratoid and straight. Septal grooves and interseptal ridges are present on the epitheca.

Ontogeny and Internal Structures.—The axial structure in all known ontogenetic stages consists of a prominent, elongate, dilated median septal lamella joining the cardinal and counter septa, and a few septal lobes originating from other major septa. The number of major septa at a particular diameter is shown in Text-figure 39. The major septa are non-dilated. Minor



Text-figure 39.—Relation between number of major septa (n) and coral diameter in *Bodophyllum neumani* n. sp.

septa extend a short distance beyond the narrow stereozone. The tabulae are mostly complete and moderately convex upward. Complementary plates (see B. Neuman, 1969, p. 6) are present in some specimens.

Microstructure.—The microstructure is unknown because of poor preservation.

Discussion.—*Bodophyllum neumani* n. sp. is distinguished from other species of the genus (see B. Neuman, 1969) by its more elongate and prominent median septal lamella. *B. shorti* n. sp., from the ?Gamachian (Upper Ordovician) of Missouri, differs in having longer minor septa and a median lamella that is slightly dilated, irregular, and not connected to the cardinal or counter septa in late stages.

***Bodophyllum*? sp.**

Plate 14, figures 7–9

Specimen.—YPM 28763.

Occurrence.—Upper Ordovician (lower to middle Ashgill): *Stenopareia* faunal zone, White Head For-

mation; Grande Coupe, 2.4 km northwest of Percé, Québec, Canada.

Description.—The small coral has an area on the cardinal side where it was attached to a brachiopod. In early stages a few septal lobes are present. In intermediate and late stages a moderately dilated median septal lamella joins the cardinal and counter septa, and a few septal lobes originate from other major septa. In the late stage, 25 major septa are present. The major septa are non-dilated. Minor septa are confined to the moderately broad stereozone. Tabulae are present.

Microstructure.—Septal fibers are not distinguishable. Lamellae are developed in the stereozone.

Discussion.—This specimen resembles *Bodophyllum* in having a median septal lamella connecting the cardinal and counter septa, but the assignment is questionable because the axial structure is less dilated than is typical of the genus. A new species is not erected because only a single incomplete specimen is known.

***Bodophyllum englishheadense* n. sp.**

Plate 14, figures 10–16

Derivation of Name.—The specific name refers to English Head, Anticosti Island, Québec, where the species has been collected.

Holotype.—YPM 28764; English Bay; Twenhofel collection (Pl. 14, figs. 10–13).

Paratypes.—YPM 28765, 28766 (Pl. 14, figs. 14–16); English Head; Twenhofel collection. YPM 28767, 28768; White Cliff; Twenhofel collection.

Occurrence.—Upper Ordovician (lower to middle Ashgill): Upper member (English Head facies) of the Vauréal Formation; Anticosti Island, Québec, Canada.

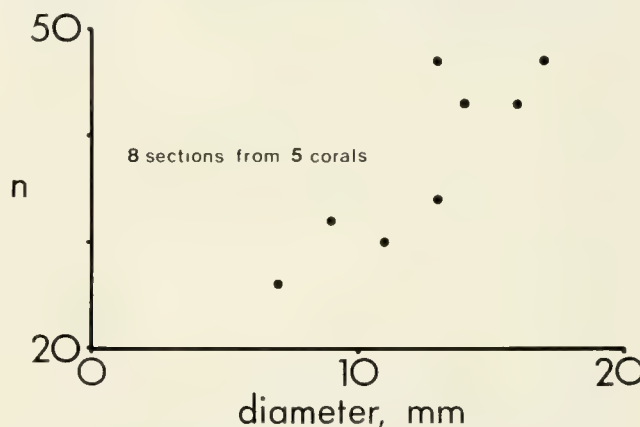
Diagnosis.—*Bodophyllum* with dense axial structure throughout ontogeny, consisting of dilated median septal lamella plus septal lobes in intermediate and late stages. Stereozone becomes very broad in late stage, attaining width of up to half the coral radius.

Description of Corals.—The largest complete specimen examined (YPM 28768) is 20 mm long and has a diameter of 14 mm immediately below the calice where 43 major septa are present. The corals are ceratoid and some become cylindrical in late stages (YPM 28764, 28765). They are straight to slightly curved. The base of attachment is centered on the cardinal side. In one specimen (YPM 28766), the two corals that are attached to a bryozoan grew into lateral contact (Pl. 14, figs. 14, 15). The epitheca has septal grooves and interseptal ridges, and coarse rugae are present on some specimens (YPM 28765, 28767). Depth of the calice is 40 percent of the coral length (YPM 28768).

A calicular boss does not appear to be developed (YPM 28765).

Ontogeny and Internal Structures.—In early stages the major septa extend to the axis where they are dilated, forming a dense axial region. In intermediate and late stages a dilated median lamella connecting the long cardinal and counter septa is the dominant element in the axial structure. It is surrounded by the dilated axial ends and septal lobes of other major septa, forming a dense axial region.

The number of major septa at a particular diameter is shown in Text-figure 40. The major septa are slightly



Text-figure 40.—Relation between number of major septa (n) and coral diameter in *Bodophyllum englishheadense* n. sp.

dilated to non-dilated. A distinct fossula is not developed. The minor septa are almost always confined to the stereozone, which is moderately broad in early stages and becomes very broad in late stages when it attains a width of up to half the coral radius (Pl. 14, fig. 13). The tabulae appear in early stages and are mostly complete, slightly convex upward, and moderately spaced (Pl. 14, fig. 10). Complementary plates (see B. Neuman, 1969, p. 6) are present.

Microstructure.—The septal fibers are well developed, and the trabeculae are inclined slightly up toward the axis. The stereozone is composed of lamellae.

Discussion.—*Bodophyllum englishheadense* n. sp. is distinct in having a very broad stereozone, far broader than that in other species of the genus (see B. Neuman, 1969).

Genus BIGHORNIA Duncan, 1957

1957. *Bighornia* Duncan, pp. 608–611.

1963. *Bighornia* Duncan. Nelson, pp. 39, 40.

1977. *Bighornia* Duncan. B. Neuman, p. 75.

1981. *Bighornia* Duncan. Elias, pp. 24, 25.

Type Species (by original designation).—*Bighornia parva* Duncan (1957, pp. 611–614). Bighorn Dolomite

(Upper Ordovician); Johnson County, Wyoming, U.S.A.

Discussion.—As presently understood, *Bighornia* includes solitary corals having a concave cardinal side, major septa that are generally completely dilated in early ontogenetic stages and may be greatly dilated even in later stages, and an axial structure with a prominent, greatly dilated median lamella. The relationship of *Bighornia* and *Densigrewingkia* B. Neuman (1969) is uncertain. The latter genus also has a concave cardinal side and a greatly dilated median septal lamella in the axial region (see B. Neuman, 1969, fig. 42). The axial structure in the latest stage of an unusually long specimen of *B. cf. B. patella* (A. E. Wilson, 1926) resembles *Grewingkia*, as does *Densigrewingkia* (see Elias, 1981, pl. 10, fig. 13). The relationship of *Bighornia* and *Bodophyllum* B. Neuman (1969) was discussed under the latter genus. B. Neuman (1977, p. 75) commented on the similarity of *Bighornia*, *Bodophyllum*, and *Dalmanophyllum* Lang and Smith (1939).

***Bighornia* cf. *B. patella* (A. E. Wilson, 1926)**

Plate 14, figures 17–24; Plate 15, figures 1–11

1926. [cf.] *Streptelasma patellum* A. E. Wilson, p. 13, pl. 2, fig. 1.
 1928. [?] *Streptelasma* aff. *breve* Ulrich in Winchell and Schuchert. Troedsson, p. 109, pl. 26, figs. 6, 7.
 1929. *Lindströmia solearis* Ladd, pp. 397–399, pl. 4, figs. 6–12.
 1943. *Holophragma anticonvexa* Okulitch, pp. 68, 69, pl. 1, figs. 11, 12.
 1956. "*Holophragma*" sp. Duncan, pl. 22, fig. 1a–c.
 1957. "*Holophragma*" sp. R. J. Ross, pl. 37, figs. 3, 5–7.
 1957. *Bighornia parva* Duncan, pp. 611–614, pl. 70, figs. 1–18.
 1959b. *Bighornia patella* (A. E. Wilson). Nelson, pl. 4, fig. 1a–d.
 1963. *Bighornia patella* (A. E. Wilson). Nelson, pp. 40, 41, pl. 11, figs. 1a–c, 2, 3a–d.
 1963. *Bighornia solearis* (Ladd). Nelson, p. 41, pl. 11, fig. 4a–d.
 1975. *Bighornia* sp. Norford and Macqueen, pl. 9, figs. 9, 10.
 1981. *Bighornia* cf. *B. patella* (A. E. Wilson). Elias, pp. 25, 26, pl. 10, figs. 1–21.

Specimens from Iowa.—SUI 2-051 (holotype of *Lindströmia solearis*); Thomas collection (Pl. 14, figs. 21s–24). SUI 2-052 (paratype of *L. solearis*); Ivson collection (Pl. 14, fig. 20s). USNM 71926 (paratype of *L. solearis*); Tysor collection (Pl. 14, figs. 17s–19).

Occurrence.—Upper Ordovician (Richmondian): Fort Atkinson Formation, Maquoketa Group; NW¼, sec. 15, T96N, R8W, 1.2 km southwest of Ossian, Winneshiek County, Iowa, U.S.A.

Description of Corals.—The largest specimen examined (USNM 71926) has a length of 23 mm. The greatest observed number of major septa is 49 in the calice at a height of 19 mm (SUI 2-051). The cardinal side is concave. The corals are trochoid and slightly curved. They are depressed throughout their length,

especially in early stages. In intermediate stages the cross-sectional length-width ratio is 1.4 (SUI 2-052). In late stages the ratio is 1.2 (USNM 71926, SUI 2-051). Two specimens (SUI 2-051, USNM 71926) have a spoon-shaped depression on the cardinal side near the tip (Pl. 14, figs. 19, 23). One of these (SUI 2-051) also has a depression on the counter side in early stages (Pl. 14, fig. 24). One small specimen (SUI 2-052) is triangulate in cross-section, but in late stages the corals become oval (SUI 2-051, USNM 71926). Depth of the calice is 30 percent of the coral length (SUI 2-051). The calicular boss is moderately convex and a prominent columella that is elongate in the cardinal-counter plane is present (Pl. 14, figs. 17s, 20s, 21s).

Internal Structures.—In intermediate and late stages the axial structure consists of a conspicuous, greatly dilated median lobe that is an extension of the counter septum, and a few other septal lobes and rare lamellae.

The number of major septa at a particular height is shown in Text-figure 41 (b, b'). The major septa are moderately dilated in the calice, where the cardinal septum is short and the cardinal fossula is narrow. Minor septa are confined to or extend a very short distance beyond the stereozone.

Microstructure.—The microstructure is not preserved in these silicified specimens.

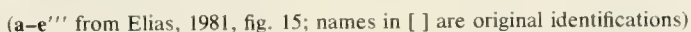
Specimens from Anticosti Island.—(All from Twenhofel collection, Anticosti Island, Québec): YPM 28769 (Pl. 15, figs. 1–6), 28770 (Pl. 15, figs. 7–11); lower member (zone 4 of Twenhofel's English Head Formation) of the Vauréal Formation; Girard Harbour. YPM 28771.

Occurrence.—Upper Ordovician (?Caradoc): Lower member of the Vauréal Formation; Anticosti Island, Québec, Canada.

Description of Corals.—The largest specimen examined (YPM 28769) has a length of 28 mm. The maximum observed number of major septa is 42 at a height of about 12 mm immediately below the calice (YPM 28770). The cardinal septum is on the concave side of the coral. The corals are trochoid and slightly curved. They are depressed throughout their length, especially in early stages. The maximum cross-sectional length-width ratio varies from 1.5 at a height of 7 mm (YPM 28769) to 2.7 at a height of about 3 mm (YPM 28770). The corals become triangulate during ontogeny. All specimens have a concave spoon-shaped area of attachment on the cardinal side near the tip (Pl. 15, fig. 7). Growth lines and weakly developed septal grooves and interseptal ridges are preserved on the epitheca. Depth of the calice is 20 (YPM 28769, Pl. 15, fig. 6) to

The number of major septa at a particular height is shown in Text-figure 41 (f, f'). The major septa are completely dilated in early stages and moderately dilated immediately below the calice. Dilation is greatest on the cardinal side. The cardinal septum becomes short in the calice. The cardinal fossula is narrow in

Discussion.—Corals of *Bighornia* from Iowa and Anticosti Island, Québec, cannot be distinguished from the forms listed in synonymy and discussed in detail by Elias (1981, pp. 25, 26). They are referred to as *B. cf. B. patella* (A. E. Wilson, 1926) until the type specimen and topotype material of *B. patella*, from



the Beaverfoot Formation (Upper Ordovician) of southeastern British Columbia, are better known. *B. cf. B. patella* occurs in the following units: Selkirk Member of the Red River Formation (upper Middle or Upper Ordovician), Garson, Manitoba; members No. 1 and 3 and upper member of the Caution Creek Formation, and member No. 1 of the Chasm Creek Formation (Upper Ordovician), northern Manitoba; Gunn Member of the Stony Mountain Formation (lower to middle Ashgill), Stony Mountain, Manitoba; shaly beds at the top of the Bighorn Dolomite (Upper Ordovician), Johnson County, Wyoming; lower member of the Vauréal Formation (?Caradoc), Anticosti Island, Québec; Fort Atkinson Formation (Richmondian), Maquoketa Group, Ossian, Iowa; and possibly in the Cape Calhoun Formation (upper Middle or Upper Ordovician), Cape Calhoun, northwestern Greenland. This species was apparently long-lived and widely distributed in the Red River-Stony Mountain Province of North America.

Family PALIPHYLLIDAE Soshkina, 1955

Genus PALIPHYLLUM Soshkina, 1955

1955. *Paliphyllum* Soshkina, pp. 121, 122.

1968. *Paliphyllum* Soshkina. B. Neuman, pp. 230, 231.

1979. *Paliphyllum* Soshkina. Laub, p. 123.

Type Species (by original designation).—*Paliphyllum primarium* Soshkina (1955, p. 122). Upper Stolbov Suite (Upper Ordovician); Podkamennaya Tunguska River, Siberian Platform, U.S.S.R.

Discussion.—*Paliphyllum* is characterized by an axial structure composed of septal lobes and lamellae, some of which are very short, with a median lamella commonly present in at least some stages. The dissepimentarium has a few series of medium-sized to large dissepiments. Septal dilation is slight throughout ontogeny.

B. Neuman (1968, p. 231) reported this genus from the Upper Ordovician of Siberia, Estonia, and Sweden, and from the Llandovery (Lower Silurian) of Estonia. Laub (1979) described three species from the middle Llandovery Brassfield Formation in Ohio and Indiana, U.S.A. The following species are known from the Ordovician of North America:

1928. *Cyathophyllum ellisense* Twenhofel, p. 119, pl. 2, figs. 10–13. Upper Ordovician (Ashgill; Gamachian): Ellis Bay Formation; Anticosti Island, Québec, Canada.

1963. *Phaulactis stummi* Nelson, pp. 43, 44, pl. 13, figs. 7, 8a–c, 9–12. Upper Ordovician: Member No. 3 of the Chasm Creek Formation, Churchill River Group; Hudson Bay Lowland, northern Manitoba, Canada.

Paliphyllum ellisense (Twenhofel, 1928)

Plate 15, figures 12–22

1928. *Cyathophyllum ellisense* Twenhofel, p. 119, pl. 2, figs. 10–13.

Holotype (by original designation).—YPM 10388A; Twenhofel's zone 9, Ellis Bay Formation; Ellis Bay, Anticosti Island, Québec; Twenhofel collection (Twenhofel, 1928, pl. 2, fig. 10).

Paratype (by original designation).—The specimen represented by Twenhofel (1928, pl. 2, fig. 11); Twenhofel's zone 9, Ellis Bay Formation; Ellis Bay, Anticosti Island, Québec; Twenhofel collection. It has not been located.

Other Specimens.—

(All from Twenhofel collection, Anticosti Island, Québec.)

YPM 28772, 28773; Ellis Bay Formation; west side of Ellis Bay.

YPM 28774, 28775; Ellis Bay Formation; Cape Henry.

YPM 28776; near base of Ellis Bay Formation; coral zone above Vauréal Falls.

YPM 10388B; Twenhofel's zone 9, Ellis Bay Formation; Ellis Bay.

The specimen represented by Twenhofel (1928, pl. 2, fig. 12; it has not been located); Twenhofel's zone 9, Ellis Bay Formation; Ellis Bay.

YPM 28777, 28778; bioherm at base of Bolton's member 6, Ellis Bay Formation; Raspberry Point.

YPM 28779–28784; Twenhofel's zone 9, Bolton's member 6, Ellis Bay Formation; Ellis Bay.

Occurrence.—Upper Ordovician (Ashgill; Gamachian): Ellis Bay Formation; Anticosti Island, Québec, Canada.

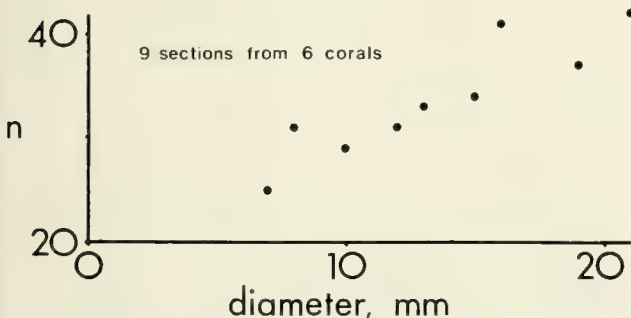
Diagnosis.—*Paliphyllum* with dissepimentarium consisting of one to three series of moderately large dissepiments inclined 45 degrees with respect to coral axis. Axial structure in early stage moderately to greatly dilated, consisting of a few septal lobes and lamellae—a median lamella may be present. In late stage axial structure is generally moderately complex with non-dilated to moderately dilated septal lobes and lamellae.

Description of Corals.—The specimens are all incomplete at both ends. The longest fragment (YPM 10388A) is 40 mm long, and the broadest is 28 mm in diameter (YPM 28783). The maximum number of major septa observed is 42 at a diameter of 21 mm (YPM 28779). The corals are cylindrical and straight. Coarse rugae are common, and some are regularly spaced at an interval of 6 to 11 mm (Pl. 15, fig. 20). Septal grooves and interseptal ridges are present on the epi-

theca. In one specimen, seven offsets resulted from peripheral increase (YPM 10388B, Pl. 15, figs. 21, 22s).

Ontogeny and Internal Structures.—In early to intermediate stages the moderately to greatly dilated axial structure consists of a few septal lobes and lamellae, and a median lamella may be present (YPM 28782). In later stages the major septa extend almost to the axis with only a few septal lobes in some specimens (YPM 28776), but commonly a moderately complex axial structure of moderately dilated to non-dilated septal lobes and lamellae develops. A few very short lamellae are present in all ontogenetic stages.

The number of major septa at a particular diameter is shown in Text-figure 42. The septa are non-dilated, but thicken at the periphery of the coral. The cardinal septum is indistinct, and a fossula is not developed. The minor septa are very long. Some septa are inter-



Text-figure 42.—Relation between number of major septa (n) and coral diameter in *Paliphyllum ellisense* (Twenhofel, 1928).

rupted in the dissepimentarium. In early stages the stereozone is narrow to moderately broad. In later stages a dissepimentarium develops. It attains a width of 30 (YPM 28779, Pl. 15, fig. 18) to 40 percent of the coral radius (Twenhofel, 1928, pl. 2, fig. 11), and consists of one to three series of dissepiments that are 1 to 4 mm long and inclined about 45 degrees with respect to the coral axis. A narrow stereozone is present on the axial side of the dissepimentarium.

The tabulae are mostly complete, very thin, closely spaced, and slightly concave upward axially (YPM 28779) to moderately convex upward (YPM 28784). Complementary plates (see B. Neuman, 1969, p. 6) are present.

Microstructure.—The septal fibers are well developed, and the trabeculae are slightly inclined up toward the axis. Lamellae are not present in the stereozone.

Discussion.—Characteristics of Baltoscandian and Siberian representatives of *Paliphyllum* have been summarized by Laub (1979, pp. 126–132), who described three species from the Lower Silurian Brassfield Formation of Ohio and Indiana. *P. ellisense* (Twenhofel, 1928) is distinguished by a dissepimentarium that consists of only one to three series of moderately large dissepiments that are inclined about 45 degrees with respect to the coral axis. *P. stummi* (Nelson, 1963), from the Upper Ordovician of northern Manitoba, differs from *P. ellisense* in having many series of small dissepiments, a moderately broad cardinal fossula, and a smaller, less complex axial region.

APPENDIX COLLECTING LOCALITIES

The localities examined in this study are listed below. They are designated using U.S. Geological Survey (USGS) topographic quadrangle maps in the United States (1:24,000 scale unless otherwise stated) and National Topographic System maps (1:50,000 series) in Canada. Coordinates following the map name are measured first east and then north from the lower left corner of the map. Locations and stratigraphic-paleontologic data are shown in Text-figures 3, 18, and 21. The stratigraphic position of collections from the Richmond Group in the Cincinnati Arch region is summarized in Table 5.

Cincinnati Arch Region, Ohio, Indiana, and Kentucky

1a.—Orangeburg and Maysville East Quads., Mason Co., KY: 426 mm E, 558 mm N (Orangeburg Quad.) to 411 mm E, 10 mm N (Maysville East Quad.). Type section of Bull Fork Fm. Roadcuts on E side of Hwy. 1443, 1.45 to 2.3 km N of junction with Hwy. 984, 3 km E of Springdale. Refer to USGS Quad. Maps GQ-588 and GQ-1006, and Peck (1966, pp. 19, 26–29).

Table 5.—Stratigraphic position of collected intervals within the Richmond Group, Cincinnati Arch region. The first number refers to the locality and the second to the stratigraphic interval (see Text-fig. 3). For USGS collections, refer to Simmons and Oliver (1967).

"Waynesville"		"Liberty"		"Whitewater-Elkhorn"	
11b-1	3-1	11a-1		5b-1	12a-8
11b-2	3-2	12c-1		5b-2	12a-9
14b-1	3-3	12d-1		5b-3	12b-1
14b-2	4-2	13b-1		5b-4	12b-2
	4-3	13b-2		5b-5	12b-3
	4-4	14a-1		12a-1	13a-1
	4-5	14a-2		12a-2	13a-2
	5b-6	USGS loc. 4662-CO		12a-3	13b-3
	5b-7	USGS loc. D1370-CO		12a-4	14a-3
	5b-8	USGS loc. 5308-CO		12a-5	14a-4
	5b-9	USGS loc. 4468-CO		12a-6	14a-5
	6c-1	USGS loc. 4545-CO		12a-7	14a-6
	7b-1	USGS loc. 4760-CO			

1b.—Manchester Islands Quad., Adams Co., OH: 68 mm E, 497 mm N. Streamcut in Isaacs Cr. just W of Hwy. 136, 1.8 km S of intersection with Hwy. 41 at Bentonville. Refer to Kohut and Sweet (1968, pp. 1459, 1460, loc. 14).

1c.—West Union Quad., Adams Co., OH: 430 mm E, 360 mm N. Roadcut on W side of Hwy. 41, 5.45 km NE of junction with Hwy. 247N in West Union. For nearby section refer to Schmidt *et al.* (1961, pp. 281–283), and Kohut and Sweet (1968, p. 1459).

2.—Bedford Quad., Trimble Co., KY: 365 mm E, 466 mm N to 336 mm E, 446 mm N. Roadcuts on N and S sides of Hwy. 42, 3.5 to 4.4 km E of Bedford. Refer to USGS Quad. Map GQ-1409, and Hattin *et al.* (1961, pp. 307–314, stop 3).

3.—Jeffersonton Quad., Jefferson Co., KY: 338 mm E, 51 mm N to 325 mm E, 52 mm N. Roadcuts and quarry on N side of Brush Run Rd., 0.25 to 0.65 km E of junction with Hwy. 1819, about 1.5 km WNW of Seatonville. Refer to USGS Quad. Map GQ-999, and Browne (1964, pp. 388, 390, 391, loc. 6a, 6b).

4.—Maud Quad., Nelson Co., KY: 70 mm E, 81 mm N to 59 mm E, 108 mm N. Includes type section of Bardstown Mbr., Drakes Fm. Roadcut on W side of Hwy. 150, 1.15 to 1.9 km NW of bridge over Beech Fork R., about 2 km NW of Fredericktown. Refer to USGS Quad. Map GQ-1043, Browne (1964, pp. 388, 390, loc. 1), Hatfield (1968, pl. 1, key sec. 6), Kohut and Sweet (1968, p. 1459, loc. 5), and Peterson (1970).

5a.—Whitcomb Quad., Franklin Co., IN: 24 mm E, 285 mm N to 42 mm E, 289 mm N. Roadcut on N side of Hwy. 101 at Bon Well Hill about 2 km NE of Brookville. Refer to Hay (1975), and Hay (1977, pp. 23–26).

5b.—Whitcomb Quad., Franklin Co., IN: 183 mm E, 508 mm N to 183 mm E, 532 mm N. Roadcuts on both sides of Hwy. 101 about 9.5 km NE of Brookville. Refer to Hay (1975), and Hay (1977, pp. 18–22).

5c.—Brookville Quad., Franklin Co., IN: 424 mm E, 292 mm N to 423 mm E, 305 mm N. Cut at Brookville Dam Spillway about 2 km N of Brookville. Refer to Hay (1975, p. 12) and Hay (1977, p. 27).

6a.—Lancaster Quad., Lincoln Co., KY: 55 mm E, 358 mm N. Type section of Ashlock Fm. Roadcuts on both sides of Hwy. 27, 1 km N of Dix R., about 5.5 km SW of Lancaster. Refer to USGS Quad. Map GQ-888, Weir, Greene, and Simmons (1965, pp. 9, 24, 25), and Kohut and Sweet (1968, p. 1459, loc. 2).

6b.—Paint Lick Quad., Garrard Co., KY: 13 mm E, 152 mm N. Type section of Drakes Fm. Roadcuts about 0.4 km S of East Fork, Drakes Cr., on E side of road leading NW from Vanhock Cemetery, about 3 km E of Preachersville. Refer to USGS Quad. Map GQ-800, and Weir, Greene, and Simmons (1965, pp. 17, 30, 31).

6c.—Lancaster and Crab Orchard Quads., Lincoln Co., KY: 405 mm E, 7 mm N (Lancaster Quad.) to 410 mm E, 574 mm N (Crab Orchard Quad.). Type section of Preachersville Mbr., Drakes Fm. Roadcuts on E side of Hwy. 39, 3.7 to 3.95 km SE of Preachersville. Refer to USGS Quad. Map GQ-888, Weir, Greene, and Simmons (1965, pp. 33–35), Simmons and Oliver (1967), and Kohut and Sweet (1968, p. 1459, loc. 4).

7a.—Union City Quad., Madison Co., KY: 232 mm E, 244 mm N to 218 mm E, 235 mm N. Roadcuts on both sides of Hwy. 974, 0.8 to 1.25 km NE of Union City. Refer to USGS Quad. Map GQ-585, and Simmons and Oliver (1967).

7b.—Union City Quad., Madison Co., KY: 52 mm E, 200 mm N to 38 mm E, 186 mm N. Roadcut on E side of road, 0.8 to 1.3 km NE of junction with Hwy. 974, about 3.5 km W of Union City. Refer to USGS Quad. Map GQ-585.

8.—Moberly Quad., Madison Co., KY: 4 mm E, 537 mm N to 43 mm E, 521 mm N. Includes type section of Terrill and Reba Mbrs.,

Ashlock Fm. Roadcuts on both sides of Hwy. 52, about 3 km E of Richmond. Refer to USGS Quad. Map GQ-664, and Weir, Greene, and Simmons (1965, pp. 27–29).

9.—Hedges Quad., Clark Co., KY: 140 mm E, 175 mm N to 152 mm E, 139 mm N. Railroad cuts on Louisville and Nashville R.R., 1.4 to 2.4 km N of Howard Cr., 0.2 to 1.2 km SE of Agawam. Refer to USGS Quad. Map GQ-1235, Weir, Greene, and Simmons (1965, pp. 18, 19), and Kohut and Sweet (1968, p. 1460, loc. 16).

10a.—Hillsboro Quad., Fleming Co., KY: 159 mm E, 194 mm N. Roadcut on E side of road along Buttermilk Branch, 1.6 km NW of Sunset. Refer to USGS Quad. Map GQ-876.

10b.—Hillsboro Quad., Fleming Co., KY: 179 mm E, 187 mm N. Roadcut on E side of road along Buttermilk Branch, 1.1 km NW of Sunset. Refer to USGS Quad. Map GQ-876.

10c.—Hillsboro Quad., Fleming Co., KY: 168 mm E, 246 mm N. Roadcut on N side of road 1.5 km S of junction of Locust Cr. and Hillsboro Branch, 4 km WNW of Hillsboro. Refer to USGS Quad. Map GQ-876.

10d.—Hillsboro Quad., Fleming Co., KY: 290 mm E, 240 mm N. Stream cut in tributary just S of road on N side of Hillsboro Branch, 1.35 km NW of Hillsboro. Refer to USGS Quad. Map GQ-876.

10e.—Hillsboro Quad., Fleming Co., KY: 227 mm E, 310 mm N. Roadcut on N side of road 0.6 km S of Locust Cr., 3.6 km NW of Hillsboro. Refer to USGS Quad. Map GQ-876.

10f.—Hillsboro Quad., Fleming Co., KY: 319 mm E, 320 mm N. Roadcut on E side of Hwy. 111, 3 km N of Hillsboro. Refer to USGS Quad. Map GQ-876.

11a.—Milan Quad., Ripley Co., IN: 16 mm E, 305 mm N to 0 mm E, 308 mm N. Roadcuts on E and W sides of Hwy. 50, 1.1 to 1.5 km W of Laughery Cr. at Versailles. Refer to Hattin *et al.* (1961, pp. 334, 347–349), and Hatfield (1968, pl. 1, key sec. 2).

11b-1.—Milan Quad., Ripley Co., IN: 80 mm E, 372 mm N. Stream cut on S side of Falling Timber Cr., 0.4 km upstream from Laughery Cr., about 2.3 km NE of Versailles.

11b-2.—Milan Quad., Ripley Co., IN: 103 mm E, 379 mm N. Stream cuts on S and N sides of Falling Timber Cr., 1.1 to 1.2 km upstream from Laughery Cr., about 2.8 km NE of Versailles.

11b-3.—Milan Quad., Ripley Co., IN: 108 mm E, 390 mm N. Stream cut on N side of Falling Timber Cr., 1.4 to 1.5 km upstream from Laughery Cr., about 3.1 km NE of Versailles.

12a.—Richmond Quad., Wayne Co., IN: 364 mm E, 448 mm N. Stream cut at Thistlewaite Falls on West Fork of Whitewater R. just S of bridge in Spring Grove. Refer to Cumings (1908, p. 662), and Hay (1975, p. 23).

12b.—Richmond and New Paris Quads., Wayne Co., IN: 392 mm E, 103 mm N (Richmond Quad.) to 37 mm E, 134 mm N (New Paris Quad.). Stream cuts along Elkhorn Cr. between Straight Line Rd. and Hwy. 227, about 6 km S of Richmond. Refer to Cumings (1908, pp. 657, 658, 660), and Hay (1975, p. 26).

12c.—Richmond Quad., Wayne Co., IN: 175 mm E, 156 mm N. Stream cuts at Blue Clay Falls on creek just S of Hunt Rd., 0.55 km W of Salisbury Rd., about 7 km SW of Richmond. Refer to Hay (1975, p. 20).

12d.—Liberty Quad., Wayne Co., IN: 148 mm E, 496 mm N to 152 mm E, 501 mm N. Roadcut on E side of Smithfield Rd., 0.1 to 0.25 km N of intersection with Potter Shop Rd., 0.4 km E of Abington. For nearby section refer to Hay (1975, p. 19).

13a.—Fairborn Quad., Greene Co., OH: 128 mm E, 211 mm N. Railroad cut primarily on S side of New York Central R.R., 0.1 km N of Wright Bros. Memorial, about 6 km SW of Fairborn. Refer to Utgaard and Perry (1964, p. 35, loc. 21), and Kohut and Sweet (1968, p. 1459, loc. 10).

13b.—Fairborn Quad., Greene Co., OH: 119 mm E, 215 mm N.

Cut on S bank of Mad R., 0.1 km SW of Huffman Dam, about 6 km SW of Fairborn. Refer to Kohut and Sweet (1968, p. 1459, loc. 10).

14a.—Clarksville Quad., Clinton Co., OH: 253 mm E, 83 mm N to 263 mm E, 65 mm N. Cut on N side of Cowan Cr., 0.2 to 0.75 km downstream from Cowan L. spillway, about 4.7 km ESE of Clarksville.

14b.—Oregonia Quad., Warren Co., OH: 70 mm E, 195 mm N to 63 mm E, 184 mm N. Roadcuts primarily on W side of road just S of Hwy. 171 leading to picnic area on Little Miami R., about 1.7 km NW of Ft. Ancient State Memorial. Refer to Wolford (1930, pp. 304–307), and Kohut and Sweet (1968, p. 1459, loc. 11).

Burkesville, Kentucky

15a.—Waterview Quad., Cumberland Co., KY: 452 mm E, 104 mm N. Roadcut on E side of Hwy. 61, 1.3 km S of junction with Hwy. 90E at Burkesville. Refer to USGS Quad. Map GQ-286, and for nearby section refer to Jillson (1951).

15b.—Waterview Quad., Cumberland Co., KY: 412 mm E, 211 mm N. Roadcut on S side of new Hwy. 90, 2.2 km E of junction with Hwy. 691, about 1.3 km NW of Burkesville. Refer to USGS Quad. Map GQ-286.

15c.—Waterview Quad., Cumberland Co., KY: 422 mm E, 215 mm N. Roadcut on N side of new Hwy. 90, 2.4 km E of junction with Hwy. 691, about 1.2 km NW of Burkesville. Refer to USGS Quad. Map GQ-286.

15d.—Waterview Quad., Cumberland Co., KY: 330 mm E, 205 mm N. Outcrop just E of Cary house, 0.4 km N of junction of Hwys. 90 and 691, about 3.5 km W of Burkesville. Refer to USGS Quad. Map GQ-286, and Jillson (1953).

Goodlettsville-Gallatin Area, Tennessee

16a.—Goodlettsville Quad., Sumner Co., TN: 128 mm E, 533 mm N and 134 mm E, 542 mm N. Roadcuts on W and E sides of Hwy. I65, 2.4 km N of Goodlettsville N interchange. For nearby sections refer to Bassler (1932, p. 122), and C. W. Wilson (1949, pp. 234, 236, sec. 5).

16b.—White House Quad., Sumner Co., TN: 138 mm E, 4 mm N. Roadcut on W side of Hwy. I65, 3.45 km N of Goodlettsville N interchange. For nearby sections refer to Bassler (1932, p. 122), and C. W. Wilson (1949, pp. 234, 236, sec. 5).

16c.—Gallatin Quad., Sumner Co., TN: 254 mm E, 414 mm N. Roadcut on W side of Dobbins Pike, 2.75 km S of Graball. For nearby sections refer to Bassler (1932, p. 127).

Little Bay de Noc, Michigan

17a.—Peninsula Point Quad. (1:62,500), Delta Co., MI: 28 mm E, 420 mm N. Outcrop on E shore of Little Bay de Noc just W of road, 2.3 km N of Stonington. Refer to Foerste (1918, p. 98, Rheinland section), Hussey (1926, pp. 116, 117, 133, 142, loc. 17), and Hussey (1950, pp. 16–20, stop 7).

17b.—Rapid River Quad. (1:62,500), Delta Co., MI: 168 mm E, 59 mm N. Federal Forest Quarry No. 2 just W of Co. Hwy. 511, 0.5 km S of Stonington lookout tower. Refer to Kesling (1975, p. 8, loc. 4, pl. 1, figs. 3, 4, p. 27, map 1), and for nearby section refer to Hussey (1926, pp. 116, 117, 146, loc. 11), and Hussey (1950, pp. 21, 22, stop 8).

17c.—Rapid River Quad. (1:62,500), Delta Co., MI: 169 mm E, 75 mm N. Outcrops on E and W sides of road, 0.4 km N of intersection near Stonington lookout tower. Refer to Hussey (1926, pp. 116, 117, 145, 146, loc. 12).

Drummond Island, Michigan

18a.—Drummond SE Quad., Drummond Is., MI: 135 mm E, 416 mm N and 115 mm E, 411 mm N. Samples collected at exposure on shore 0.3 km SE of Reynolds Point; paleocurrent data collected on shore in NE part of Reynolds Bay, 0.3 km SW of Reynolds Pt. For nearby section refer to Hussey (1952, pp. 49, 50).

18b.—Drummond Quad., Drummond Is., MI: 383 mm E, 477 mm N. Exposure on shore 0.3 km E of Poe Point. Refer to Hussey (1952, pp. 50, 51).

18c.—Drummond Quad., Drummond Is., MI: 86 mm E, 437 mm N. Exposure on shore at Hay Point. For nearby section refer to Hussey (1952, p. 50).

Manitoulin Island, Ontario

19a.—Little Current Sheet (No. 41 H/13), Manitoulin Is., Ont.: 184 mm E, 284 mm N. Roadcuts on both sides of Hwy. 68, 4.9 km SE of Sheguiandah. Refer to Ontario Division of Mines (ODM) Map 2247.

19b.—Little Current Sheet (No. 41 H/13), Manitoulin Is., Ont.: 227 mm E, 283 mm N. Roadcut on Hwy. 68, 7.1 km SE of Sheguiandah. Refer to ODM Map 2247.

19c.—Little Current Sheet (No. 41 H/13), Manitoulin Is., Ont.: 28 mm E, 325 mm N. Roadcut on S side of road, 4.5 km W of Sheguiandah. Refer to ODM Map 2247.

19d.—Kagawong Sheet (No. 41 G/16), Manitoulin Is., Ont.: 375 mm E, 344 mm N. Roadcut on W side of road into Kagawong, 0.3 km N of junction with Hwy. 540. Refer to ODM Map 2246, Foerste (1916, p. 110, loc. 40), and Liberty and Shelden (1968, p. 7, stop 1).

19e.—Kagawong Sheet (No. 41 G/16), Manitoulin Is., Ont.: 613 mm E, 331 mm N. Roadcut on E side of Hwy. 540, 1.4 km N of Honora. Refer to ODM Map 2246.

19f.—Kagawong Sheet (No. 41 G/16), Manitoulin Is., Ont.: 384 mm E, 324 mm N. Roadcut on N and S sides of Hwy. 540, 1 km SE of junction with road into Kagawong. Refer to ODM Map 2246, and for nearby section refer to Foerste (1916, pp. 108, 109, loc. 38).

M61a.—Little Current Sheet (No. 41 H/13), Manitoulin Is., Ont.: 293 mm E, 2 mm N. Laurentian Univ. collection. Refer to ODM Map 2247.

M75.—Little Current Sheet (No. 41 H/13), Manitoulin Is., Ont.: 60 mm E, 283 mm N. Laurentian Univ. collection at ditch on SE corner at intersection of E–W and N–S roads, 1 km E of Pike Lake. Refer to ODM Map 2247.

Missouri

20a.—Cape Girardeau NE Quad., Cape Girardeau Co., MO: 44 mm E, 276 mm N. Type section of Leemon Formation. Outcrop in gully behind barn on Short's farm. Refer to Amsden (1974, pp. 19–21, loc. K), and Thompson and Satterfield (1975, pp. 76, 77, loc. 3).

20b.—Neelys Landing Quad., Cape Girardeau Co., MO: 71 mm E, 251 mm N. Outcrops on Blue Shawnee Creek, 1.7 km E of New Wells. Refer to Amsden (1974, pp. 20–22, loc. U), and Thompson and Satterfield (1975, pp. 79, 80, loc. 4).

21a.—Clarksville Quad., Pike Co., MO: 326 mm E, 572 mm N. Roadcut on west side of Hwy. 79, N edge of Clarksville. Refer to Amsden (1974, pp. 6, 9, loc. E), and Thompson and Satterfield (1975, p. 91, loc. 6).

21b.—Louisiana Quad., Pike Co., MO: 312 mm E, 312 mm N. Type section of Noix Limestone. Outcrop at Clinton Springs, S edge of Louisiana. Refer to Amsden (1974, pp. 6, 9, loc. B), and Thompson and Satterfield (1975, p. 90, loc. 7).

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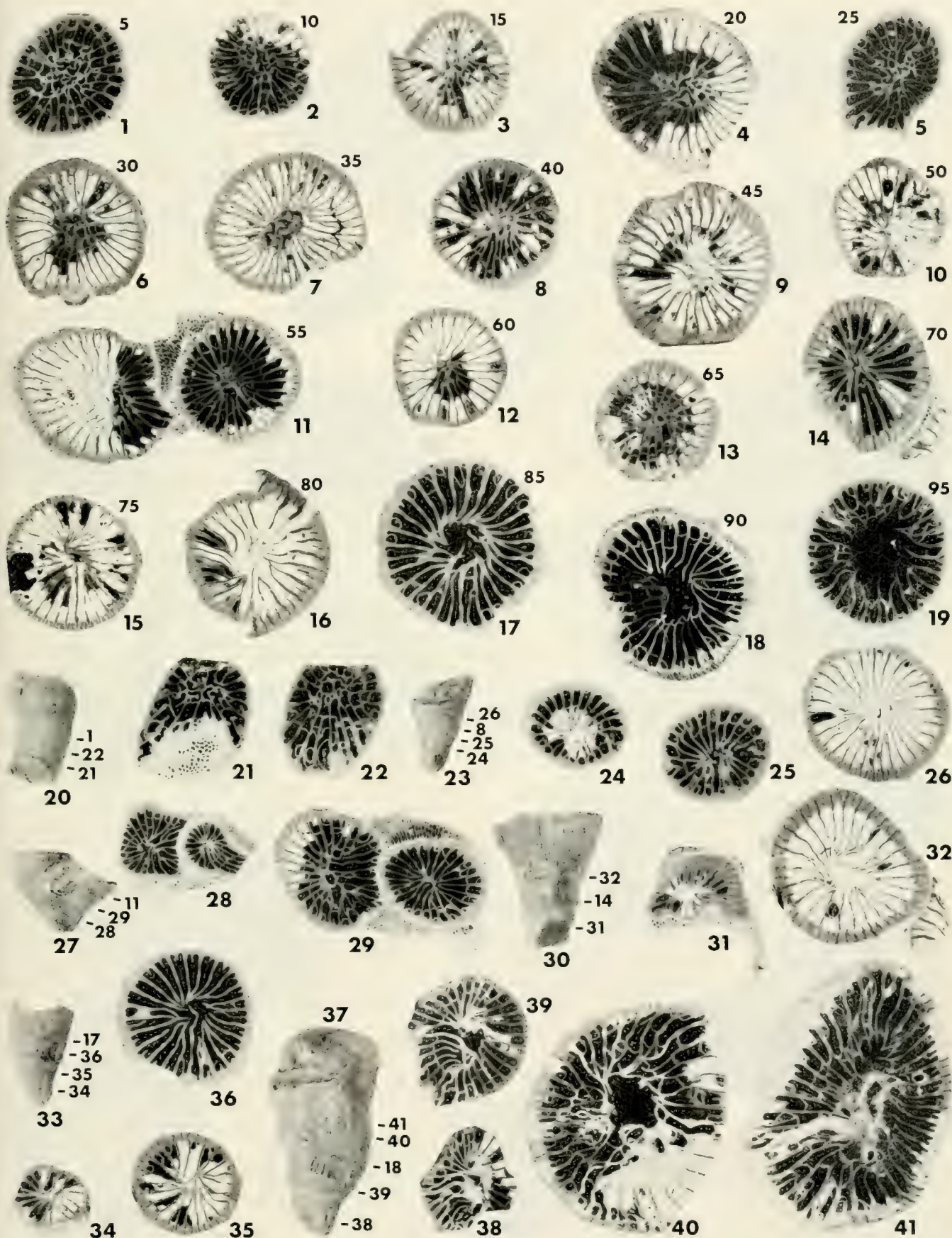
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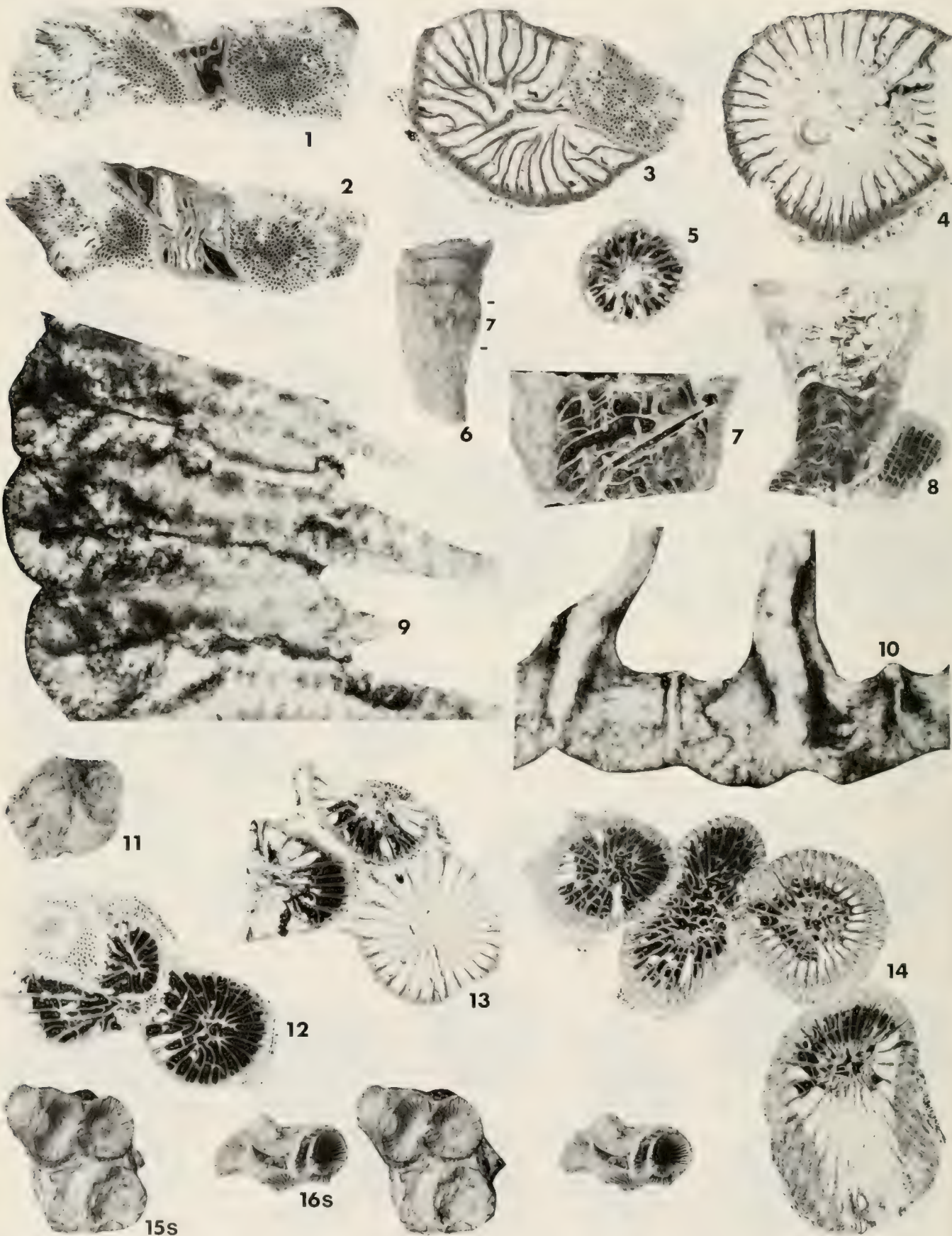
PLATES

Exterior views are of specimens coated with ammonium chloride. A stereopair is denoted by “s” following the figure number. Transverse and longitudinal sections are negative prints of thin sections unless otherwise stated. Transverse sections are oriented as they appear looking from the top of the coral towards the tip. Small numbers and lines beside exterior views and longitudinal sections refer to positions and figure numbers of illustrated sections. When the interval from which a specimen was collected is given, the first number indicates the locality and the second designates the stratigraphic interval (see “Appendix: Collecting Localities”, and Text-figs. 3, 18, 21). If this publication is photo-reduced, note that in the original the dimensions of plates, excluding margins, are 7 inches by 9 inches.

EXPLANATION OF PLATE 1

Figure	Page
1-41. <i>Streptelasma divaricans</i> (Nicholson, 1875b)	25, 53
(Richmond Group; Cincinnati Arch region)	
1-19. Axial region comparative scale and values (small numbers 5, 10 . . . 95), transverse sections, $\times 3$ (see p. 26). 1, UCGM 45072; interval 12a-1. 2, UCGM 45061; interval 11b-1. 3, UCGM 45014; interval 4-2. 4, UCGM 45037; interval 5b-2. 5, UCGM 45137; interval 13b-2. 6, UCGM 45004; interval 2-1. 7, UCGM 45133; interval 13b-1. 8, UCGM 45074; interval 12a-1. 9, UCGM 45028; interval 5b-1. 10, UCGM 45054; interval 5b-9. 11, UCGM 45084; interval 12a-2. 12, UCGM 45008; interval 3-2. 13, UCGM 45611; interval 13a-1. 14, UCGM 45018; interval 4-3. 15, UCGM 45057; interval 10c-1. 16, UCGM 45020; interval 4-4. 17, UCGM 45086; interval 12a-2. 18, UCGM 45034; interval 5b-2. 19, UCGM 45019; interval 4-3.	
20-22. UCGM 45072; interval 12a-1. 20, exterior alar view, cardinal side left, $\times 1$ (see p. 23). 21, 22, transverse sections, cardinal side down, $\times 3$.	
23-26. UCGM 45074; interval 12a-1. 23, exterior alar view, cardinal side right, $\times 1$. 24-26, transverse sections, cardinal side down, $\times 3$.	
27-29. UCGM 45084; interval 12a-2. 27, exterior view, $\times 1$ (see p. 23). 28, 29, transverse sections, $\times 3$.	
30-32. UCGM 45018; interval 4-3. 30, exterior view, $\times 1$ (see p. 23). 31, 32, transverse sections, $\times 3$.	
33-36. UCGM 45086; interval 12a-2. 33, exterior view, cardinal side left, $\times 1$ (see p. 23). 34-36, transverse sections, cardinal side down, $\times 3$.	
37-41. UCGM 45034; interval 5b-2. 37, exterior alar view, cardinal side left, $\times 1$. 38-41, transverse sections, cardinal side down, $\times 3$.	



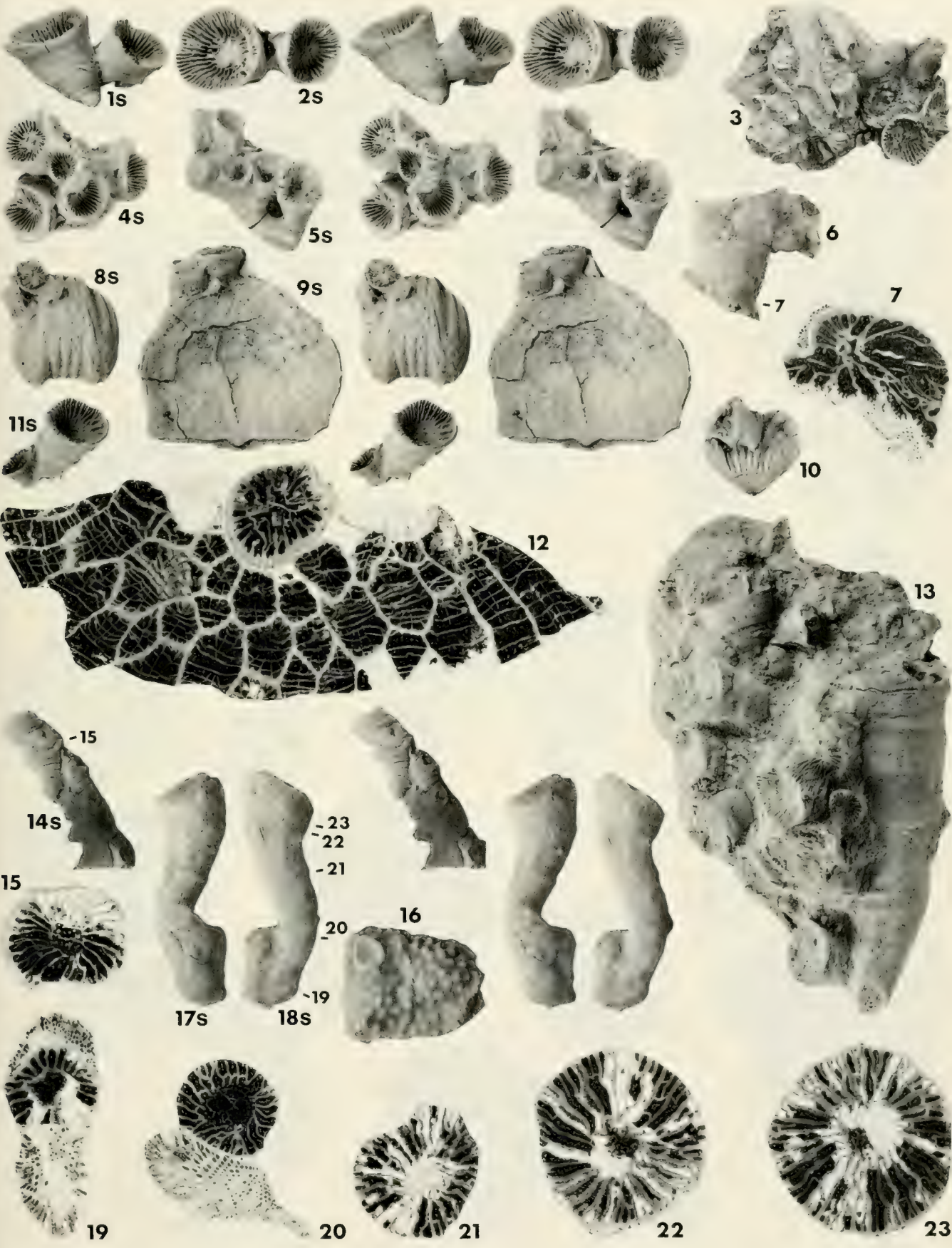


EXPLANATION OF PLATE 2

Figure	Page
1-16. <i>Streptelasma divaricans</i> (Nicholson, 1875b) 25, 53 (Richmond Group; Cincinnati Arch region)	
1-4. UCGM 45128; interval 13a-2; transverse sections, $\times 3$ (see p. 23).	
5. USNM 84868a [syntype of <i>S. divaricans-angustatum</i> Foerste (1909)]; "Whitewater" strata, Osgood, Indiana; transverse section, $\times 3$.	
6, 7. UCGM 45013; interval 4-2. 6, exterior alar view, cardinal side left, $\times 1$. 7, longitudinal section, cardinal side left, $\times 3$.	
8. UCGM 45145; "Whitewater" strata, Hueston Woods Park, Oxford, Ohio; longitudinal section, cardinal side right, $\times 3$.	
9. UCGM 45024; interval 4-5; transverse photomicrograph, late ontogenetic stage, dilated major and minor septa in lateral contact in stereozone, $\times 31$.	
10. UCGM 45080; interval 12a-2; transverse photomicrograph, late ontogenetic stage, non-dilated major and minor septa separated by U-shaped lamellae in stereozone, $\times 31$.	
11. UCGM 45646; interval 12a-5; exterior view, $\times 1$ (blastogeny shown in Text-fig. 26; see p. 23).	
12, 13. UCGM 45093; interval 12a-4; transverse sections, $\times 3$. 12, increase demonstrated by incomplete wall between two corallites on left. 13, corallites separated later in ontogeny.	
14, 15s. USNM 311660; "Whitewater" strata, NW of Oxford, Ohio. 14, transverse section showing opening in wall developing between two central corallites, $\times 3$. 15s, exterior view of calices showing complete connection between two central corallites later in ontogeny, $\times 1$.	
16s. USNM 311661; "Whitewater" strata, NW of Oxford, Ohio; exterior view showing rejuvenance in calice of right corallum, $\times 1$.	

EXPLANATION OF PLATE 3

Figure	Page
1-23. <i>Streptelasma divaricans</i> (Nicholson, 1875b)	25, 53
(Richmond Group: 1-13, Cincinnati Arch region; 14, 15, Little Bay de Noc, Michigan; 16-23, Manitoulin Island, Ontario)	
1s, 2s. FMNH UC413 (lectotype); "Cincinnati Group, Cincinnati, Ohio"; ×1. 1s, exterior lateral view. 2s, exterior view of calices.	
3. UCGM 45121; interval 13a-1; bedding surface, coralla in life position on brachiopod fragment (lower right) and on bryozoan (lower left), ×1 (see p. 23).	
4s. USNM 50816; Bardstown, Kentucky; cluster of coralla, ×1.	
5s. USNM 311628; "Waynesville" strata, near Clarksville, Ohio; cluster partly overgrown by host bryozoan, ×1 (see p. 23).	
6, 7. UCGM 45100; interval 12a-5. 6, exterior view of coral with large base of attachment on bryozoan, ×1. 7, transverse section, coral wall not developed at site of attachment to bryozoan, ×3 (see p. 23).	
8s. USNM 40086; "Whitewater" strata, Oxford, Ohio; coralla attached to <i>Lepidocyclus? capax</i> , ×1 (see p. 23).	
9s. USNM 135767; "Whitewater" strata, Richmond, Indiana; coralla attached to <i>Rafinesquina alternata</i> , ×1 (see p. 23).	
10. UCGM 45066; interval 11b-3; coral attached to <i>L. ? capax</i> , ×1 (see p. 10).	
11s. USNM 84869C; "Whitewater" strata, Osgood, Indiana; note talons on right corallum, ×1 (see p. 23).	
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13. USNM 42517; Oxford, Ohio; bedding surface, some coralla attached to large specimen of <i>Grewingkia canadensis</i> , ×1 (see pp. 13, 23).	
14s, 15. USNM 78449, 78449a; Bay de Noc Mbr., Stonington Fm., Stonington, Michigan. 14s, coralla attached to <i>Rafinesquina</i> , ×1 (see p. 29). 15, transverse section, ×3.	
16. GSC 66635; Meaford beds, upper mbr., Georgian Bay Fm., locality M61a; coral attached to bryozoan, ×1 (see p. 33).	
17s-23. GSC 66636; Meaford beds, upper mbr., Georgian Bay Fm., locality M61a. 17s, exterior alar view, cardinal side right, ×1 (see p. 33). 18s, exterior alar view, cardinal side left, ×1 (see p. 33). 19-23, transverse sections, cardinal side down, ×3.	





EXPLANATION OF PLATE 4

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1-3. <i>Streptelasma leemonense</i> n. sp. (Leemon Fm., locality 20a, Cape Girardeau Co., Missouri)	56
1, 2. UCGM 45614 (holotype); transverse sections, $\times 4$ (see p. 39).	
3. UCGM 45615 (paratype); transverse section, $\times 4$.	
4-6. <i>Streptelasma</i> sp. UCGM 45616; Leemon Fm., locality 20a, Cape Girardeau Co., Missouri; transverse sections, $\times 4$.	39, 56
7-22. <i>Streptelasma subregulare</i> (Savage, 1913) (7s, 8, Cyrene Fm., near Edgewood, Missouri; 9-22, Leemon Fm., locality 20b, Cape Girardeau Co., Missouri)	57
7s, 8. UI X-851 (holotype); $\times 1$. 7s, exterior view of calice, cardinal side down. 8, exterior counter view showing tabulae where wall is broken.	
9. UCGM 45628; longitudinal section, cardinal side left, $\times 2$ (see p. 39).	
10-13. UCGM 45622. 10, exterior cardinal view, $\times 1$ (see p. 39). 11, exterior alar view, cardinal side right, $\times 1$ (see p. 39). 12, 13, transverse sections, cardinal side down, $\times 2$ (see p. 39).	
14-18. UCGM 45619. 14, exterior cardinal view, $\times 1$ (see p. 39). 15, exterior alar view, cardinal side left, $\times 1$ (see p. 39). 16, 17, transverse sections, cardinal side down, $\times 2$ (see p. 39). 18, longitudinal section, cardinal side left, $\times 2$ (see p. 39).	
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9. YPM 28705; exterior view, note talons near base on right side and coarse rugae, $\times 1$ (see pp. 45, 46).	
10-13. YPM 28706. 10, polished longitudinal section, cardinal side left, $\times 1$ (see p. 45). 11-13 (YPM 28706A-C), transverse sections, cardinal side down, $\times 1.5$.	
14-18. YPM 28709. 14, exterior alar view, cardinal side right, $\times 0.5$ (see p. 45). 15-18 (YPM 28709A-D), transverse sections, cardinal side down, $\times 1.5$.	



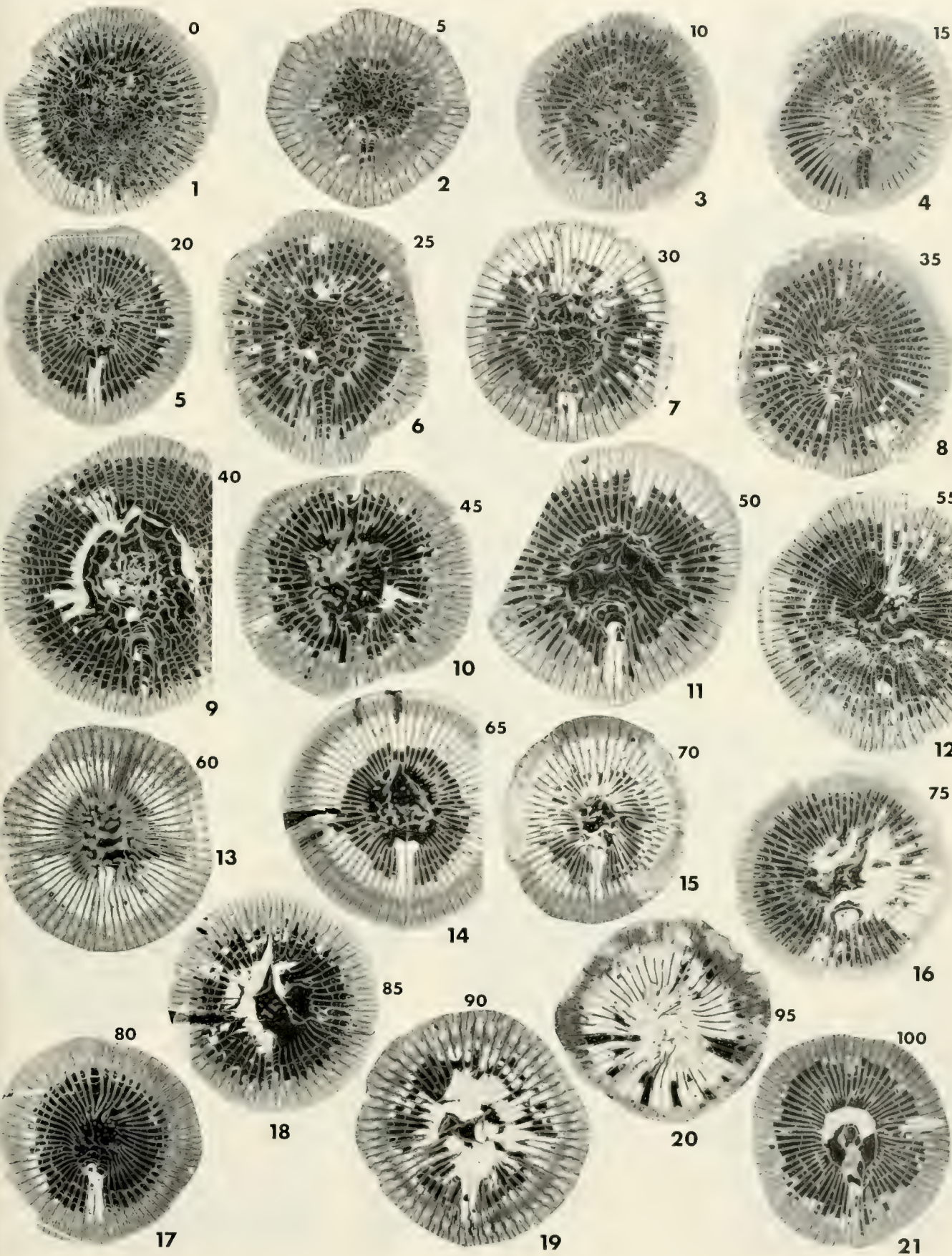


EXPLANATION OF PLATE 6

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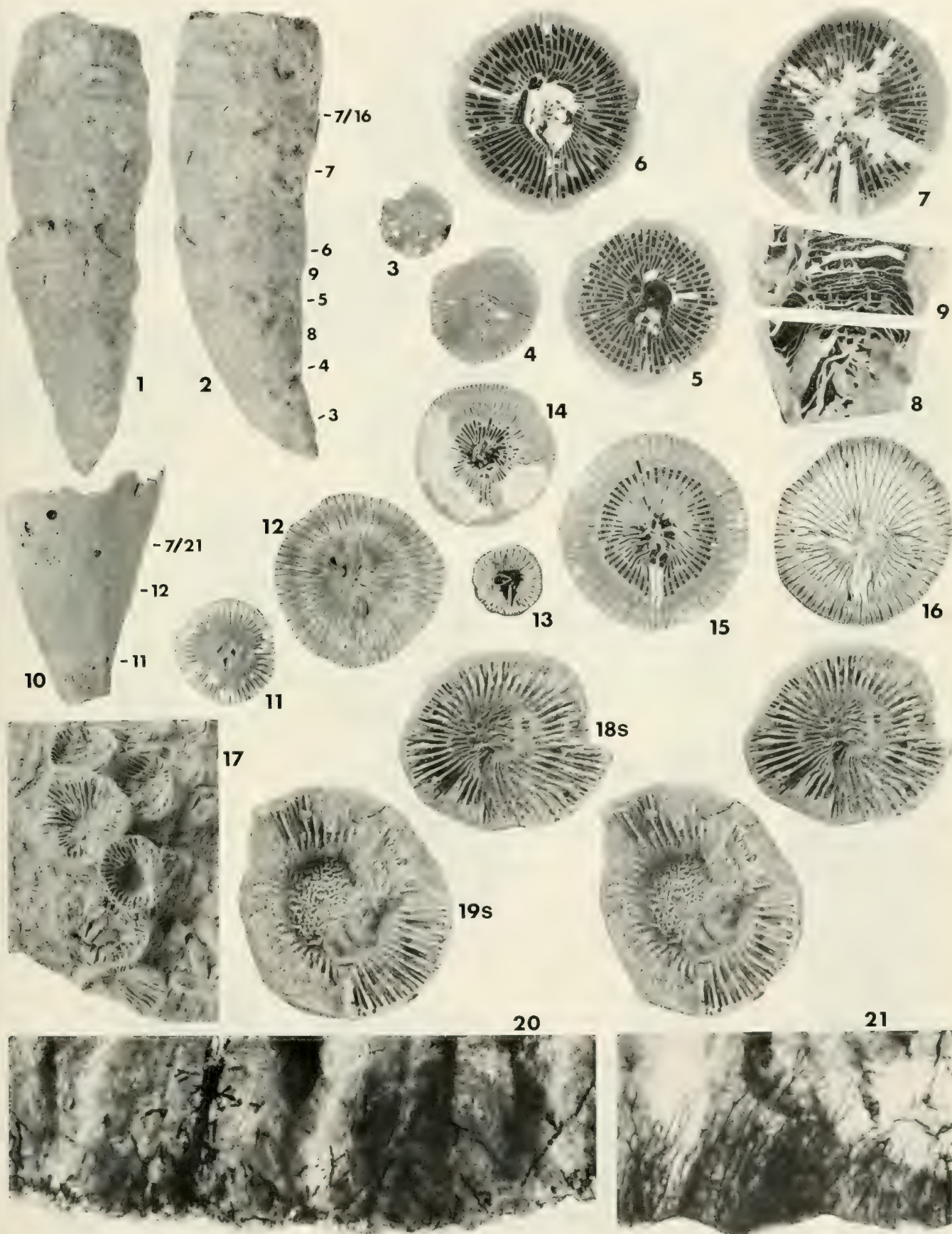


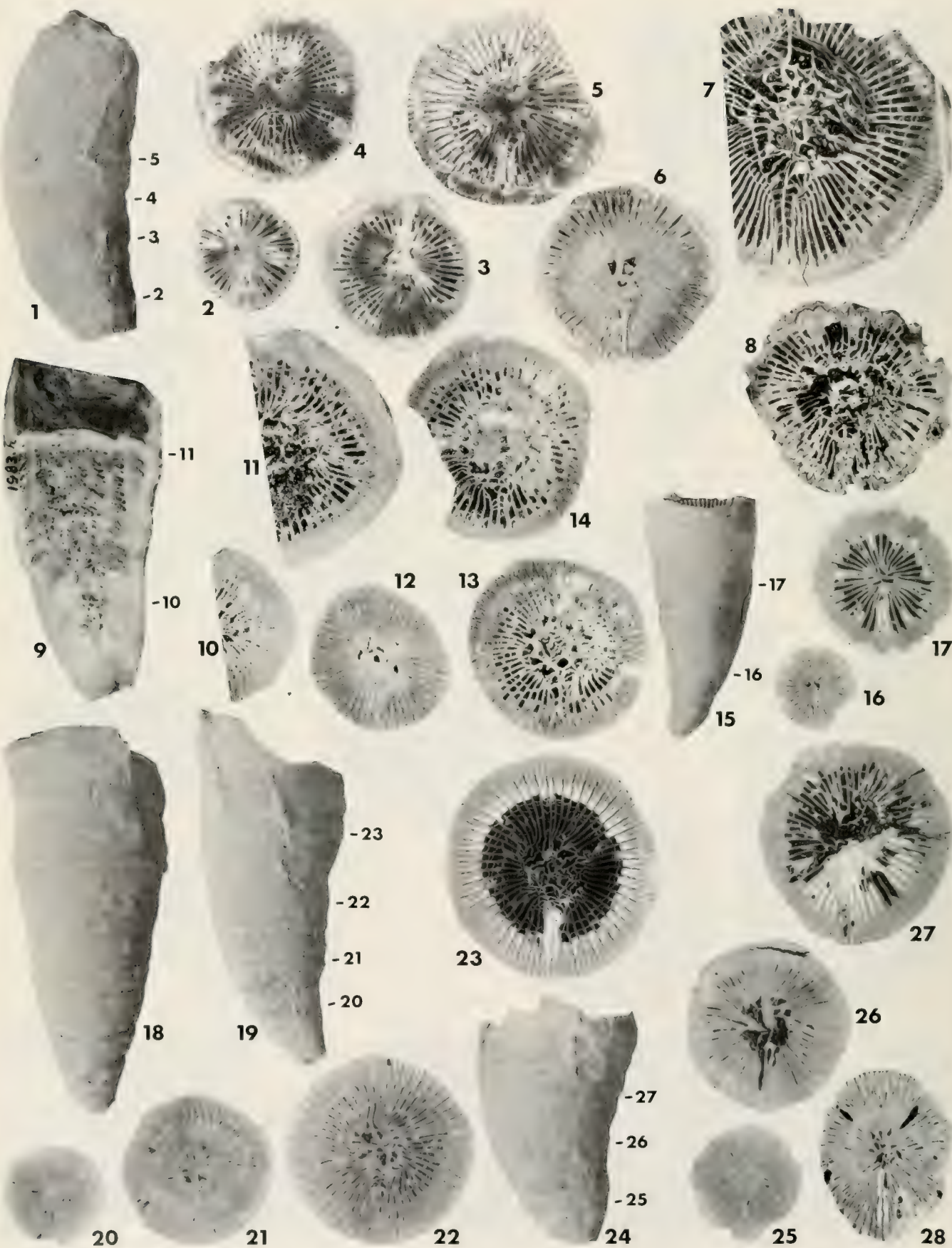
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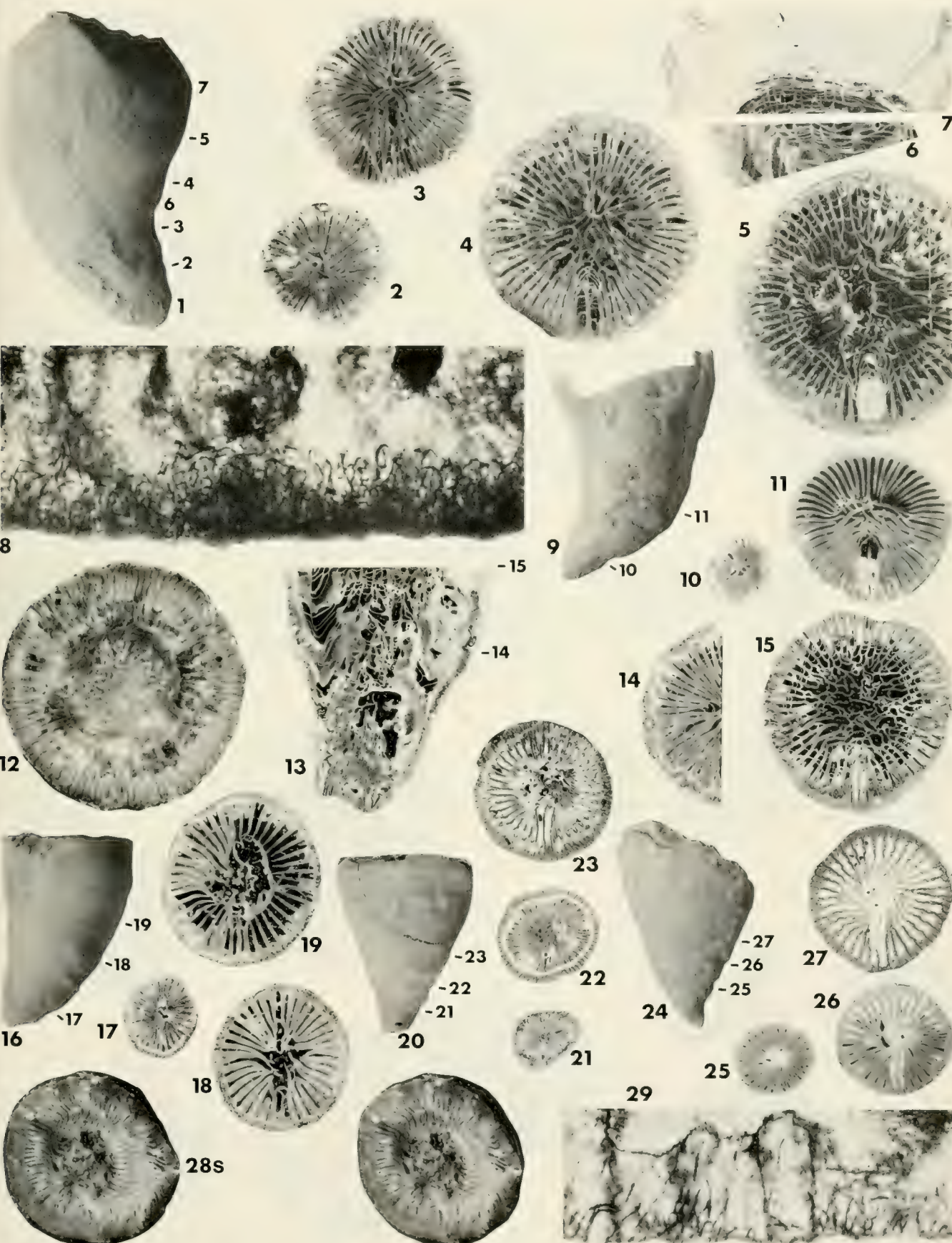


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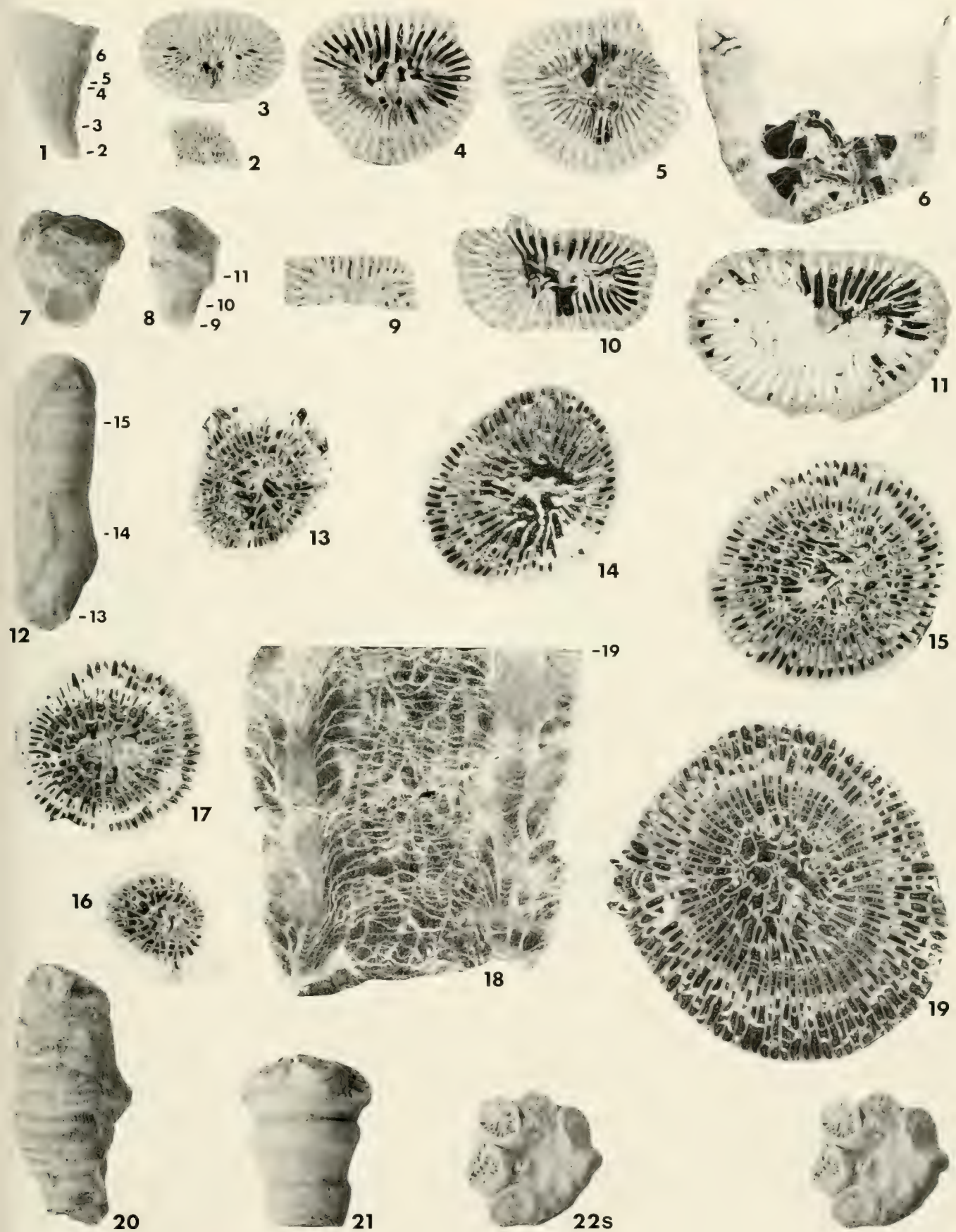


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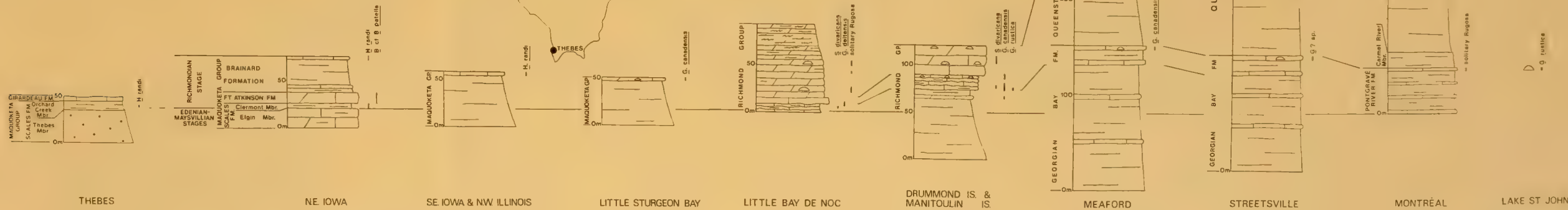
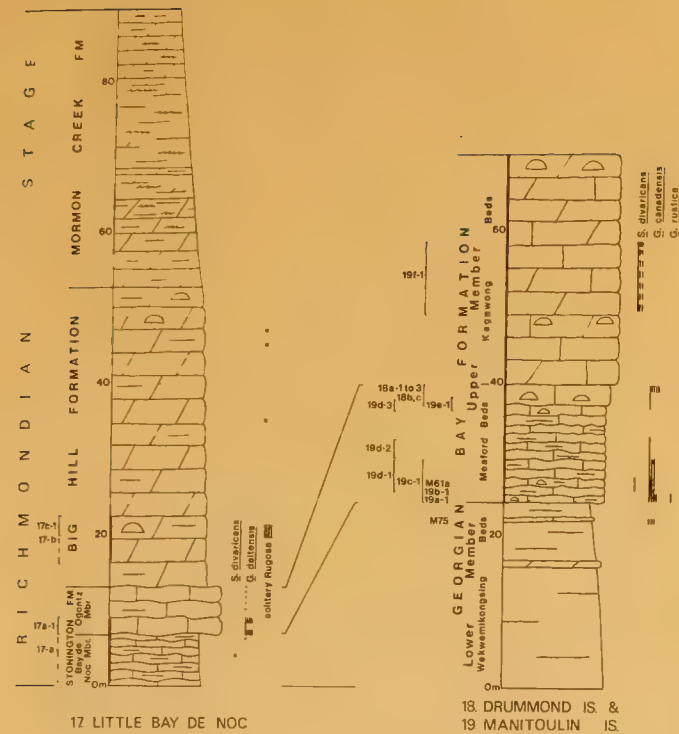
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Text-figure 18.-- Richmondian stratigraphic sections (all to the same scale) and distribution of solitary rugose corals (*Streptelasma*, *Heliclasma*, *Grewinkia*, and *Bighornia*) in Illinois, Iowa, Wisconsin, Michigan, Ontario, and southwestern Québec. Sections 17 and 18-19 are shown in detail (both to the same scale) in the upper left (see "Appendix: Collecting Localities", for further information). For explanations of symbols see legends in Text-figure 3

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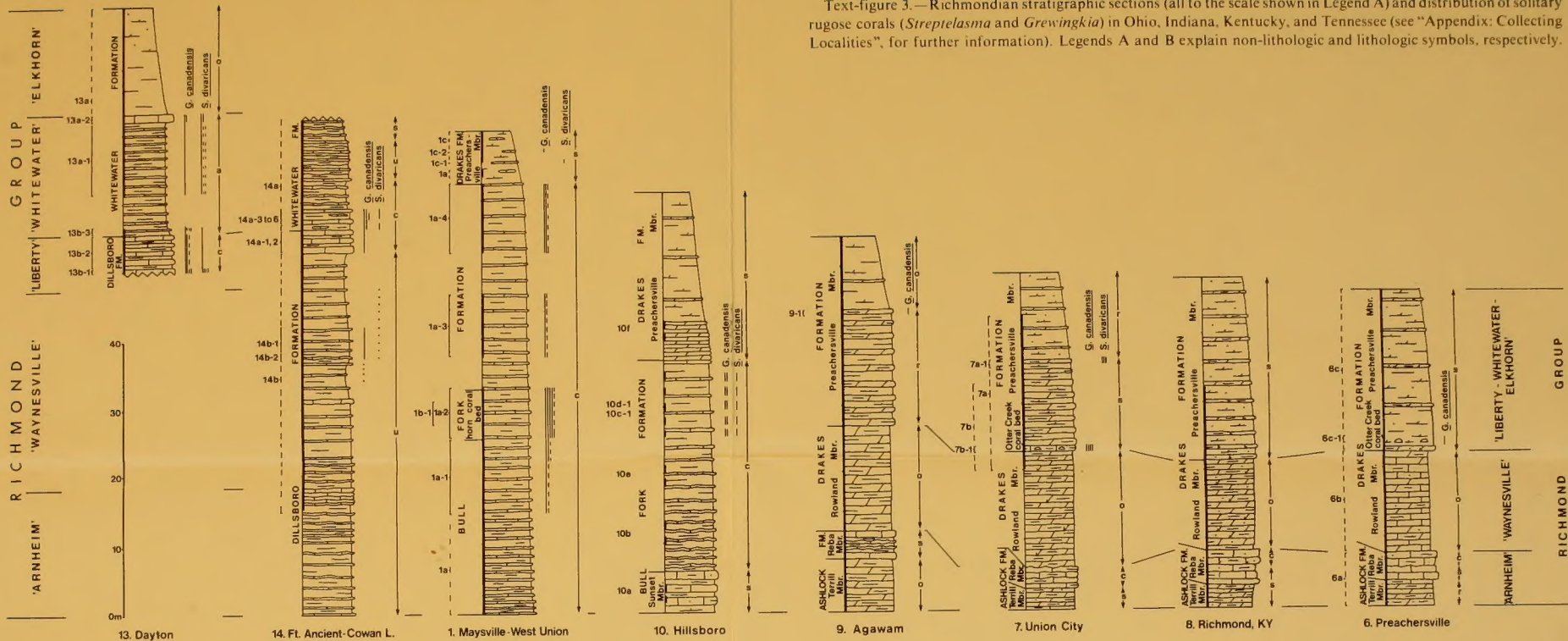
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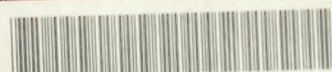
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